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GENERATION OF LONG TIME CREEP DATA ON REFRACTORY ALLOYS AT ELEVATED TEMPERATURES

NINTH QUARTERLY REPORT

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
UNDER CONTRACT NAS 3-2545

TRW EQUIPMENT LABORATORIES
CLEVELAND, OHIO

NAS-CR 54773

NINTH QUARTERLY REPORT

FOR

June 26, 1965 to September 26, 1965

GENERATION OF LONG TIME CREEP DATA OF REFRACTORY ALLOYS AT ELEVATED TEMPERATURES

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Prepared for:

National Aeronautics and Space Administration
Contract No. NAS 3-2545

Technical Management

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October 8, 1965

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TABLE OF CONTENTS

FOREWORD

The work described herein is being performed by TRW Inc. under the sponsorship of the National Aeronautics and Space Administration under Contract NAS 3-2545. The purpose of this study is to obtain design creep data on refractory metal alloys for use in advanced space power systems.

The program is administered for TRW Inc. by E. A. Steigerwald, Program Manager. J. C. Sawyer is the Principal Investigator, and R. R. Ebert contributed to the program.

I. INTRODUCTION

Space electric power systems depend upon the use of refractory metals in a variety of component areas. A critical property parameter in the design of these systems is the long-time creep strength at very low partial pressures of oxygen and nitrogen. Since contamination of refractroy metal alloys can occur under conditions of 10^{-6} Torr, vacuums better than 10^{-8} Torr must be used to obtain creep measurements which are employed in the design of space components. The purpose of this program is to generate long-time creep data on selected refractory alloys which have potential use in advanced power systems. Emphasis has been placed on testing sheet alloys which can be employed for cladding or tubing applications and on forgeable, high-strength turbine alloys.

The design of the creep test units capable of operating at vacuums less that 1×10^{-8} Torr and temperatures up to 3200°F has been previously described. This report presents a summary of the creep data obtained to date on tungsten, tungsten-25% rhenium, Sylvania A, molybdenum-base alloys TZC and TZM, columbium-base alloys Cb132M and AS-30, and the tantalum alloy T-222.

II. MATERIALS

The types of alloys being evaluated in the creep program are given in Table 1 while a listing of chemical compositions in terms of primary alloying elements is given in Table 2. A review of the processing history of all the alloys is presented in Appendix I.

Since the tungsten base materials are being evaluated primarily for use in cladding applications, the tests were conducted on specimens machined from 0.030" sheet material. One exception to this material form was the vapor-deposited tungsten which was obtained as 1/8" dia. bar specimens.* The microstructures of the tungsten, tungsten-25% rhenium, and Sylvania A sheet materials in both the wrought as-received condition and after recrystallization are shown in Figures 1, 2, and 3. The Sylvania A sheet had a large number of surface imperfections and radiography was used in insure that defects were not present in the specimen gauge sections. Prior to creep testing the specimens were recrystallized for two hours at the 3200°F test temperature.

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* The processing history of the vapor-deposited tungsten was not available, however, the fabrication techniques and the initial structure were reported to be comparable to that described in Reference 1.

TABLE 1

Summary of Material Variables Being Evaluated in Creep Program

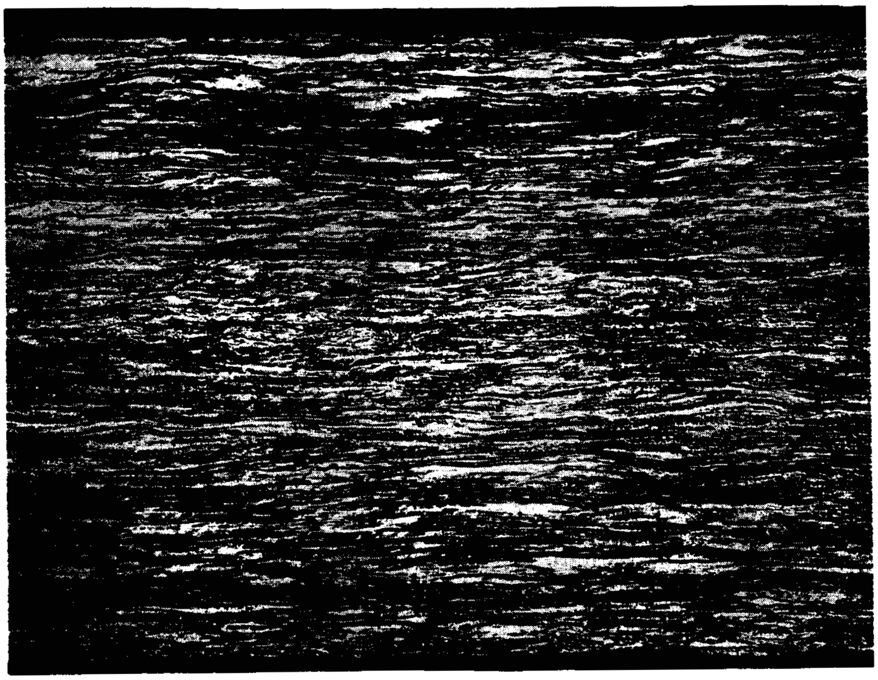
Material	Form	Test Temperature	Test Condition
Tungsten	Arc-Melted 0.030" Sheet	3200°F (1760°C)	Recrystallized 1-2 hours, 3200°F (1760°C)
Tungsten-25% Rhenium	Arc-Melted 0.030" Sheet	3200°F (1760°C)	Recrystallized 1-2 hours, 3200°F (1760°C)
Sylvania A	Powder Metallurgy 0.030" Sheet	3200°F (1760°C)	Recrystallized 1-2 hours, 3200°F (1760°C)
Tungsten	Vapor-deposited 1/8" dia. Bars	3200°F (1760°C)	As-Received
AS-30	3/4" Plate	2000-2200°F (1093-1204°C)	As-Received (stress-relieved condition)
Cb132M	3/4" Plate	2056-2256°F (1124-1235°C)	Annealed 1 hour, 3092°F (1700°C)
TZM (Climax Heat 7502)	"Pancake"Forging	2000°F (1093°C)	(Cond.1) As-received (stress-relieved condition.) (Cond.2) Annealed 1 hour, 2850°F (1566°C)
TZM-Heat KDTZM-1175 (Air Research)	"Pancake"Forging	1600-1856°F (871-1013°C)	As-received (stress-relieved, 2300°F (1260°C) 1 hour)
TZC (Heat M-80) TZC (Heat M-91)	3/4" Plate	1800-2200°F (982-1204°C)	Several test conditions
T-222*	0.030" Sheet	1800-2200°F (982-1204°C)	Recrystallized 3000°F (1649°C) 1 Hour
T-111	0.030" Sheet	1800,2000,2200°F (982,1093,1204°C)	Recrystallized 2600°F (1426°C) 1 Hour

* Originally scheduled to be tested as ST-222 plate material, program plan revised to include material as T-222 grade applicable for tubing.

TABLE 2

Chemical Composition of Alloys Being Evaluated in Creep Program (Weight %)

Material	W	Re	Cb	Mo	Ta	Hf	C	N_2	Ti	Zr	Ni	O_2 ppm	H_2 ppm
Tungsten	Bal.						.0058					9	4
Tungsten-25% Rhenium	Bal.	24.9					.0050					50	1.4
Sylvania A	Bal.					0.52	.030					20	3
TZM (Climax Heat 7502)				Bal.			.013	.011	.47	.091		20	7
TZM-Heat KDTZM-1175 (Air Research)				Bal.			.031	.0043	.61	.12		34	9
TZC (Heat M-80)				Bal.			.140	.0018	1.02	.130		41	5
TZC (Heat M-91)				Bal.			.145	.003	1.17	.274		37	10
AS-30	21.0		Bal.				.090	.010	.03	1.04	.02	60	15
Cb132M	15.6		Bal.	4.73	19.5		.150	.002		2.40		4	2
T-222	9.57				Bal.	2.93	.012	.0026				35	11
T-111	8.5				Bal.	2.30	.004	.002				55	6

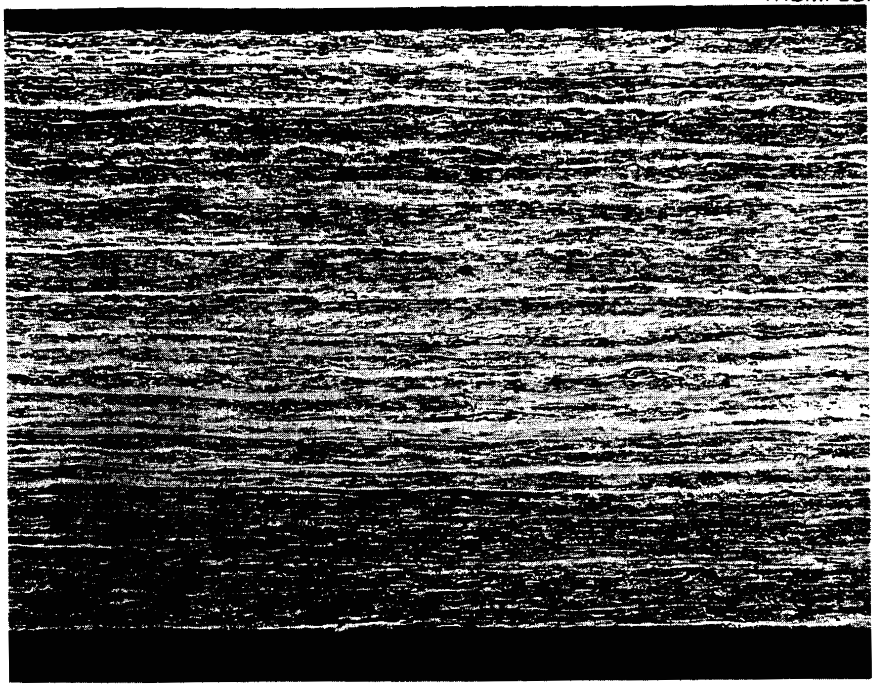


Edge Perpendicular to Rolling Direction
of As-Received Sheet.

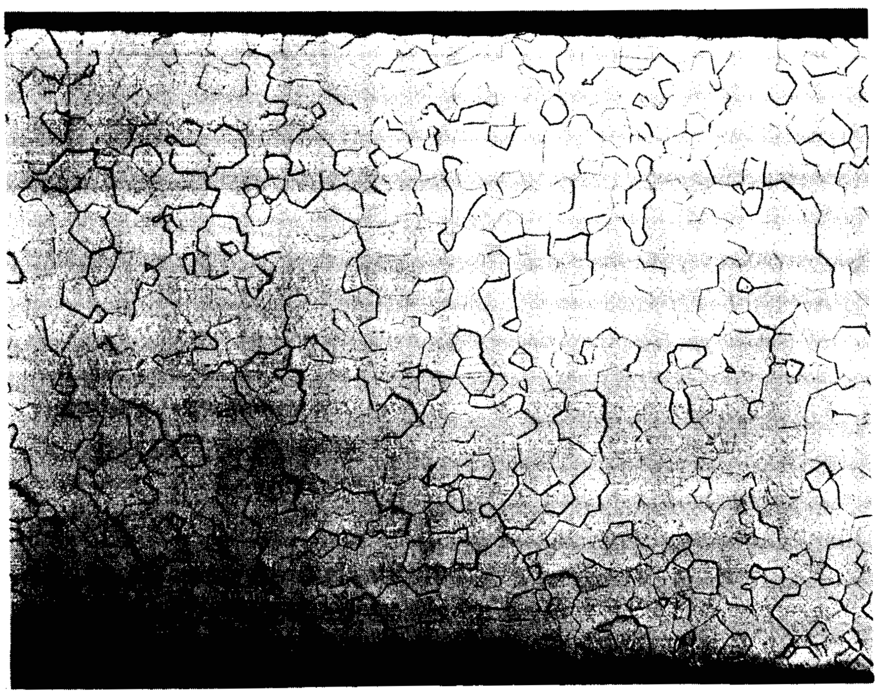
Edge Perpendicular to Surface of Sheet
Recrystallized 1 Hour, 3200°F (1760°C).

Figure 1. Microstructures of Arc-Cast Tungsten Sheet in As-Received and Recrystallized Conditions. Etchant: 15%HF, 15%H_2SO_4, 8%HNO_3, 62%H_2O. 100X.

7644



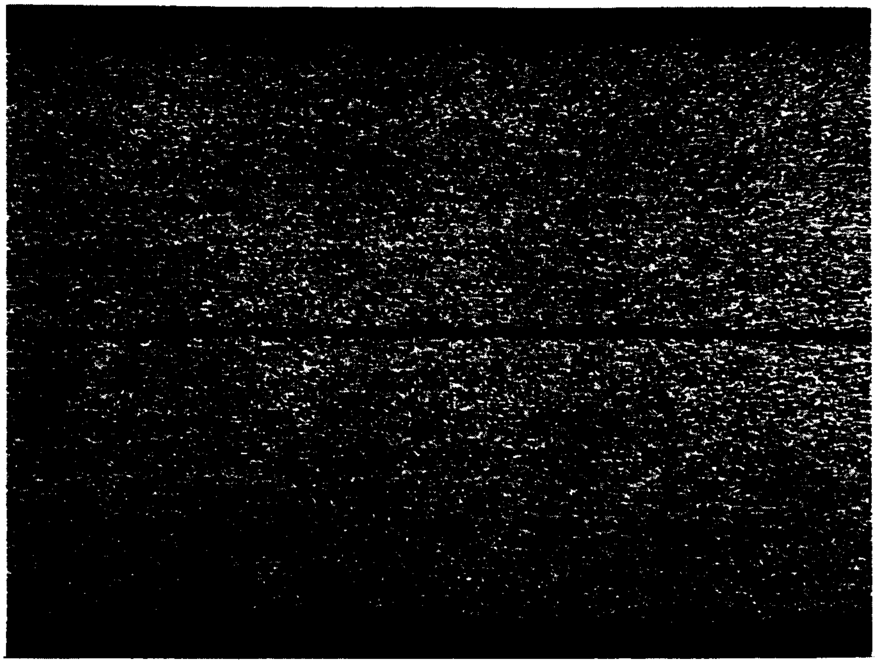
Edge Perpendicular to Rolling Direction of As-Received Sheet



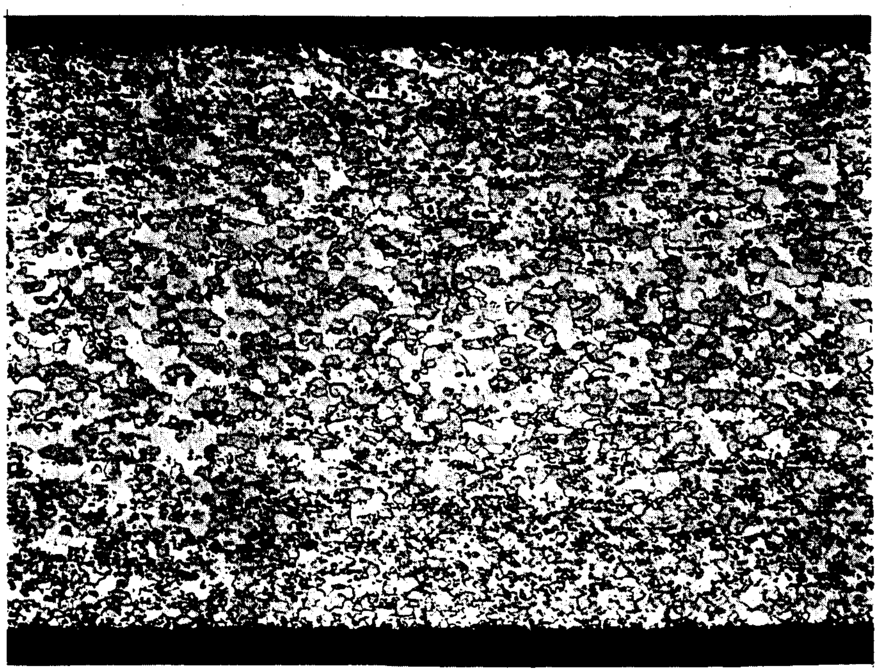
Edge Perpendicular to Rolling Direction of Sheet
Recrystallized 1 Hour at 3200°F (1760°C).

9272

Figure 2. Microstructures of Arc-Cast Tungsten-25% Rhenium Sheet in As-Received and Recrystallized Conditions. Etchant: 15%HF, 15%H_2SO_4, 8%HNO_3, 62%H_2O. 100X



Edge Perpendicular to Rolling Direction, As-Received Condition Showing Lamination in Sheet.



Edge Perpendicular to Rolling Direction, Sheet Recrystallized 1 Hour at 3200°F (1760°C).

9269

Figure 3. Microstructures of Powder Metallurgy Sylvania A Sheet in As-Received and Recrystallized Conditions. Etchant: 15%HF, 15%H_2SO_4, 8%HNO_3, 62%H_2O. 100X

Molybdenum alloy heats which can be nominally classified as TZM, but which contain significant variations in chemistry are being evaluated. The specific chemical compositions shown in Table 3 indicate that Heat 7052 had less carbon, zirconium, and titanium than Heat 1175. Both heats were obtained as disc forgings having a characteristic flow pattern shown in Figure 4. The microstructures as a function of position in the forging are presented in Figure 5 while Figures 6 and 7 typify the microstructure as a function of orientation of the specimen. In general, the structure was relatively uniform over the specimen gauge section. Testing was conducted with specimens from Heat 7502 in both the as-received condition and after annealing at 2850°F (1566°C) for one hour, while tests with Heat 1175 were performed only on the as-received alloy. Recrystallization of TZM Heat 7502, see Figure 8, revealed severe gradation in grain size from the surface to the center as a result of the variation in work across the thickness. The gauge section of the actual test specimen, however, had a relatively uniform grain size which is characterized by the bottom micrograph in Figure 8.

Although the chemical compositions were comparable, the processing history for the two heats (M-80 and M-91) of TZC alloy which were evaluated as plate material (0.700" thick) differed significantly. As described in Appendix I, the fabrication sequence for Heat M-80 involved a relatively high finishing temperature with small reductions (approximately 4%) per pass while the processing for Heat M-91 employed a lower finishing temperature and relatively large reductions. The variation in processing is reflected in both the hardness values shown with the microstructures in Figure 9 and the room temperature properties (Table 3). In the as-received condition Heat M-91 which was processed at the lower finishing temperature had higher room temperature strength properties and exhibited a greater degree of ductility. The selection of an optimum heat treatment for the TZC alloy for use in turbine applications must produce a structure which affects a suitable compromise between creep strength and resistance to brittle failure at lower temperatures where start-up operations are critical. An annealing treatment of one hour at 3092°F (1700°C) was selected for the initial creep tests on TZC. Higher annealing temperatures are capable of producing higher strengths and greater creep resistance, at the sacrifice, however, of room temperature ductility (2)*. The use of the 3092°F (1700°C) treatment prior to testing provides a mild solution treating condition which was believed sufficient to allow some strain-induced precipitation to occur during the

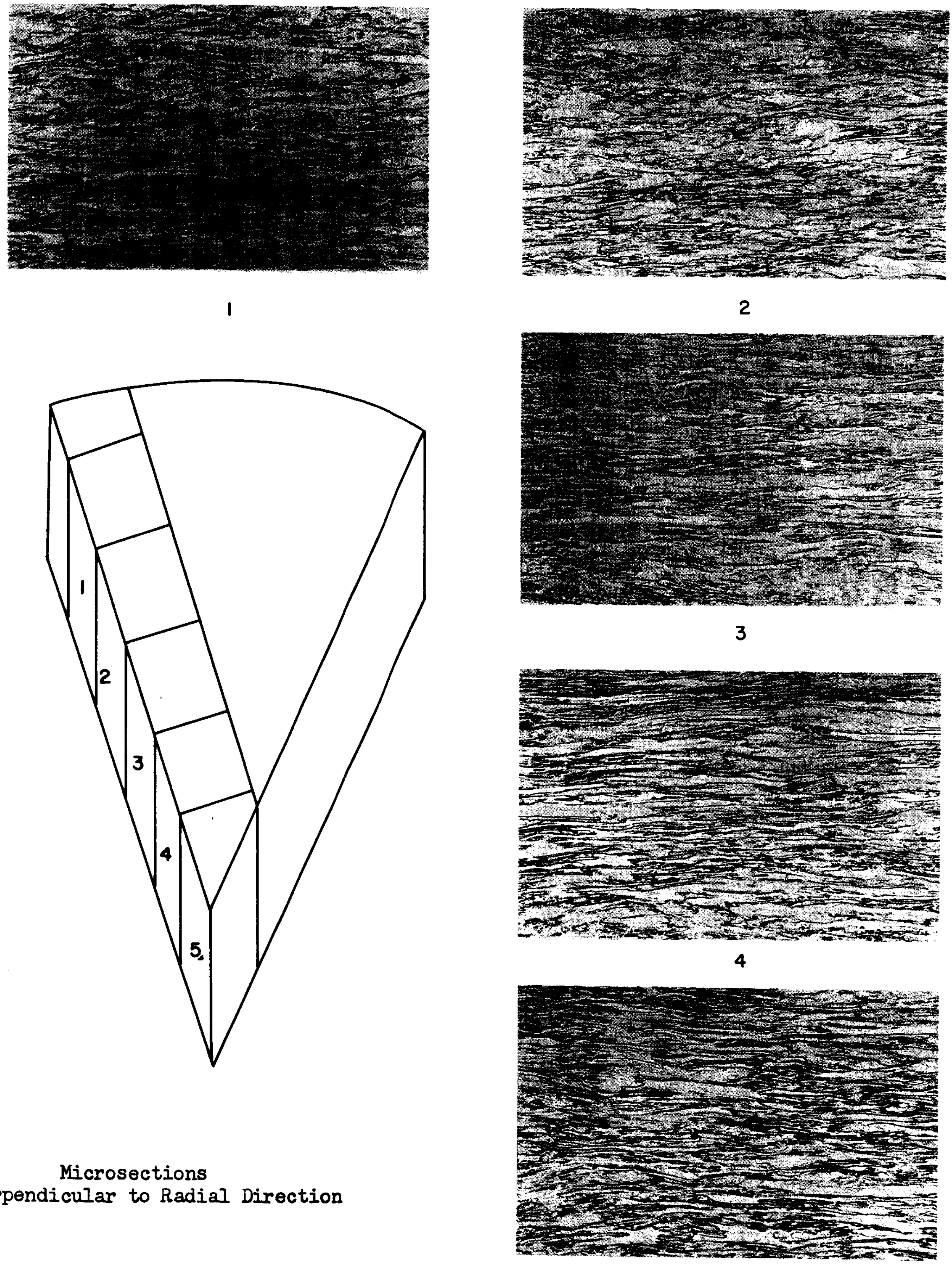
* Numbers in parentheses pertain to references in the Bibliography.

CENTER OF FORGING

OUTER EDGE OF FORGING

Figure 4. Photograph of Macroetched Section of TZM Heat No. 7502 Pancake-Forged Disc Showing Flow Lines Due to Forging. 1-1/2X

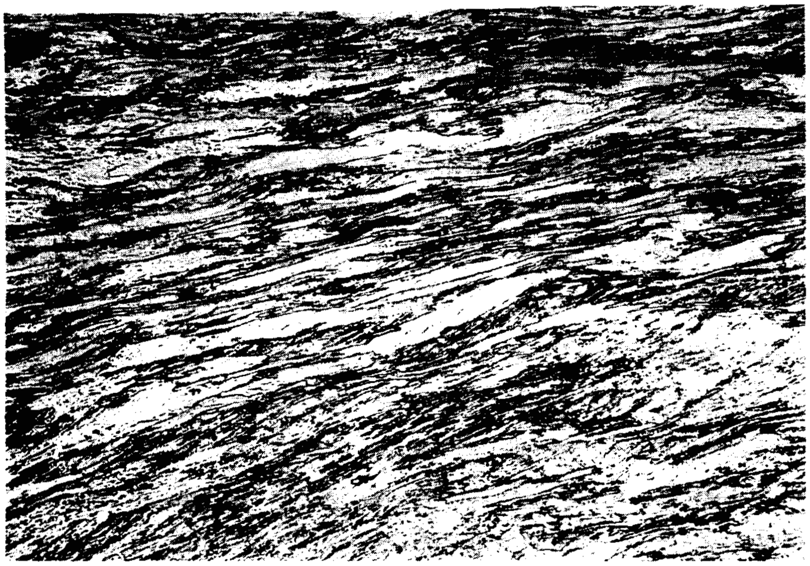
8554



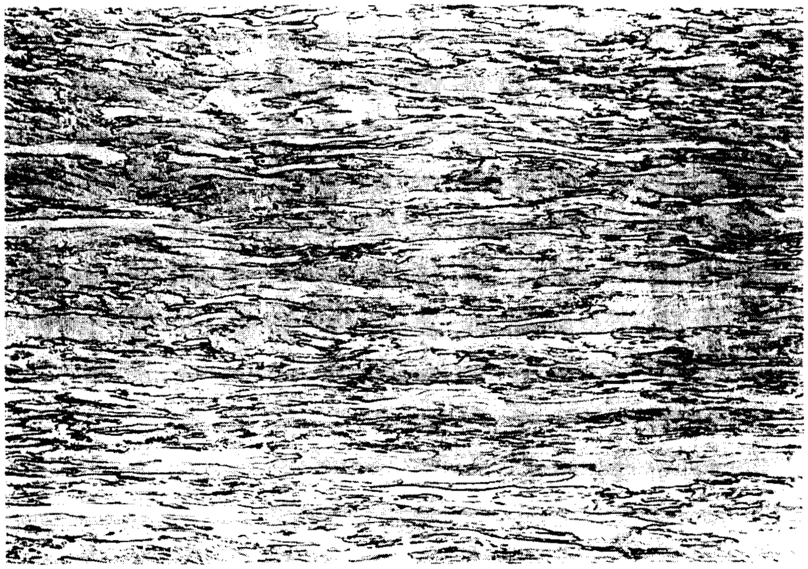
Microsections
Perpendicular to Radial Direction

8553

Figure 5. Photomicrographs Showing Etched Sections of TZM Heat 7502 Pancake Forging. 100X, Murakami's Etch. As-Received.



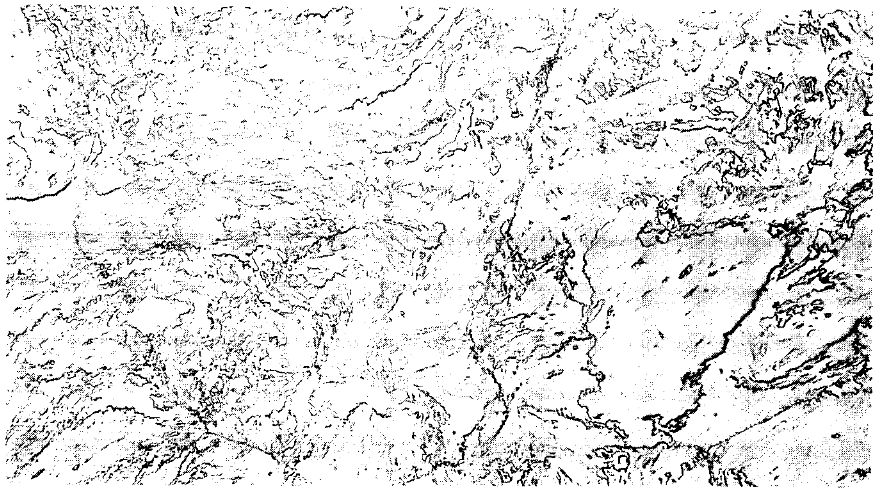
EDGE PARALLEL TO RADIAL DIRECTION



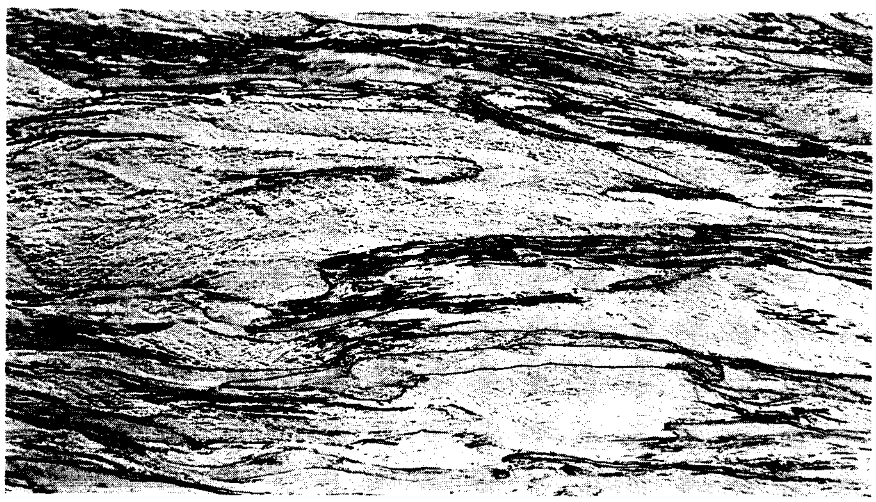
EDGE PERPENDICULAR TO RADIAL DIRECTION

Figure 6. Microstructure of TZM Forged Disc, Heat 7502, as a Function of the Orientation of the Forging. Murakami's Etch, 100X.

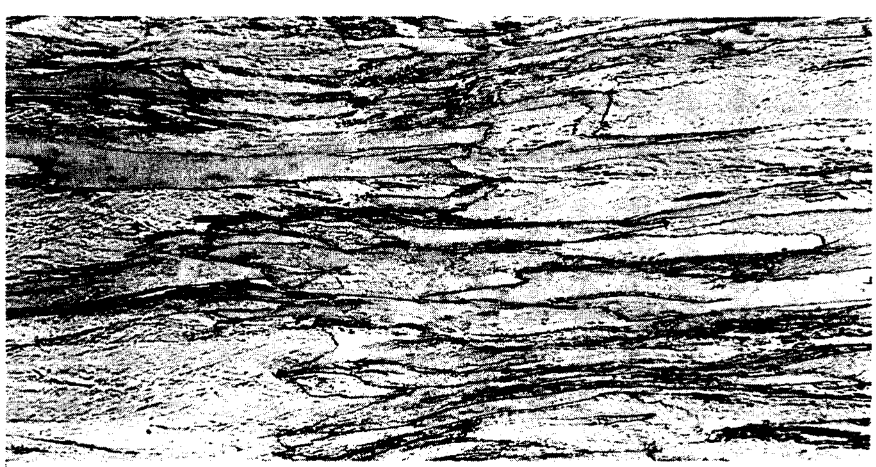
7652



Surface



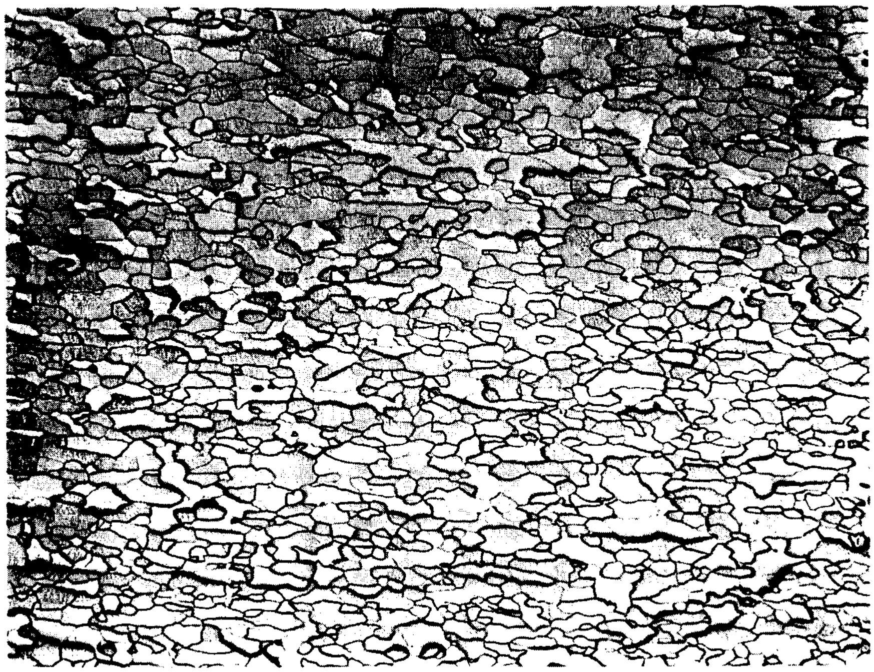
Edge Parallel to Radial Direction



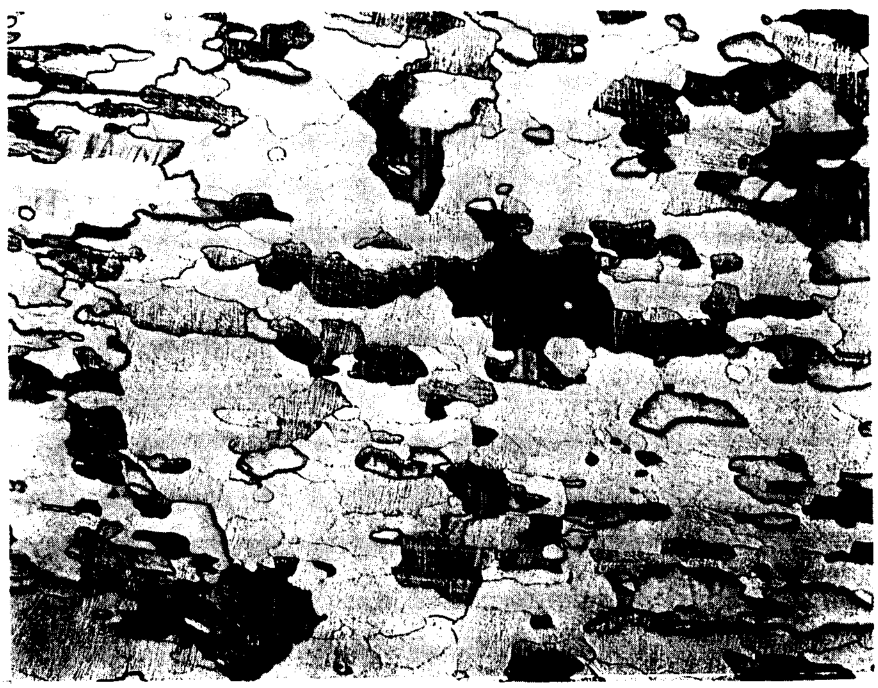
Edge Perpendicular to Radial Direction

Figure 7. Microstructures of TZM Forged Disc, Heat 1175, as a Function of Orientation in the Forging. Etchant: 15% HF, 15% H_2SO_4, 8% HNO_3, 62% H_2O. 100X

9276



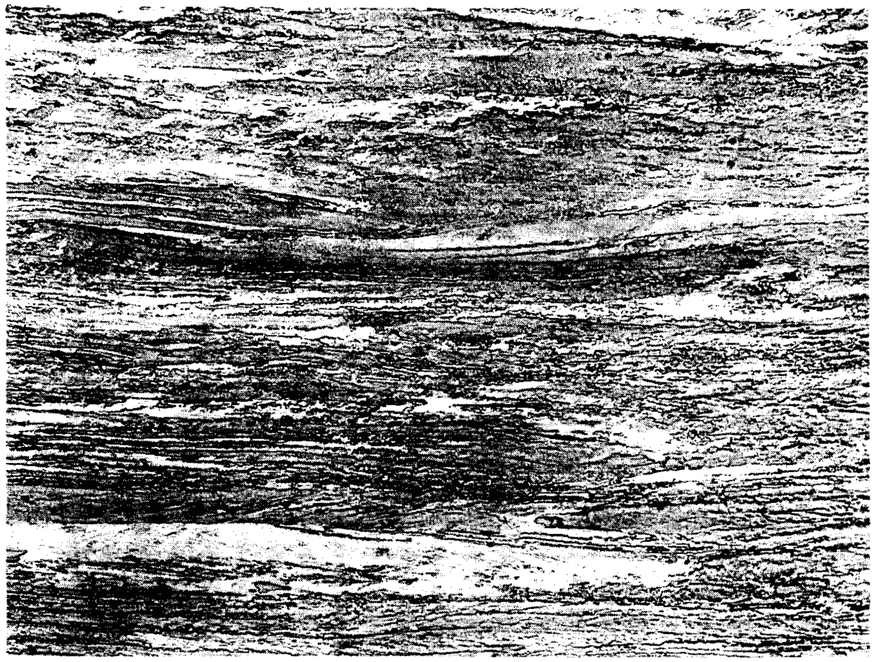
Edge of Cross Section



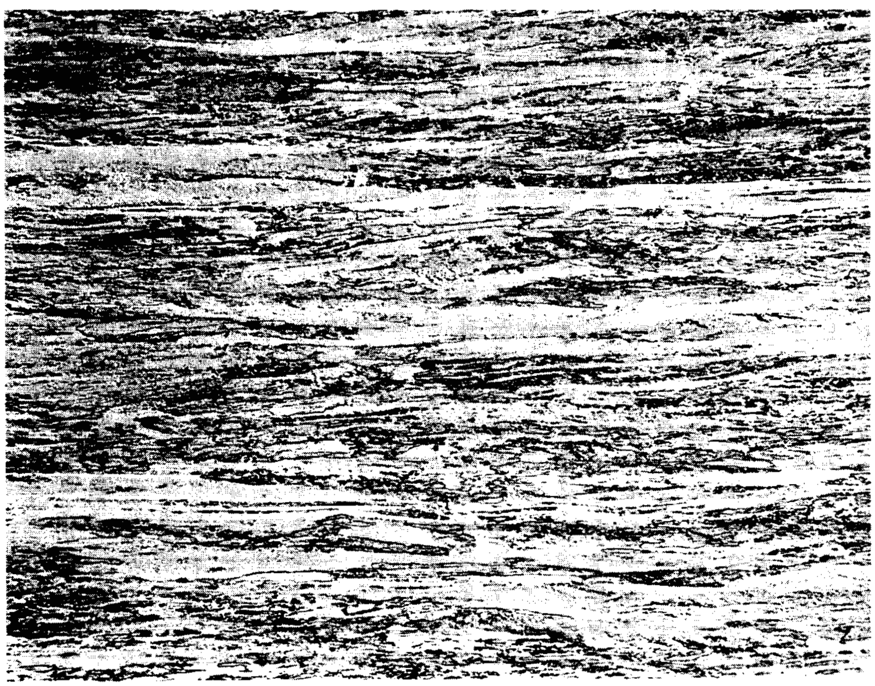
Center of Cross Section

Figure 8. Photomicrographs of TZM Forged Disc, Heat 7502, After Recrystallization for 1 Hour at 2850°F (1588°C). Murakami's Etch, 100X. Hardness 210 DPH.

9273



TZC Heat M-80, Perpendicular to Rolling Direction,
Hardness 296 DPH.



TZC Heat M-91, Perpendicular to Rolling Direction,
Hardness 385 DPH.

9267

Figure 9. Microstructures of TZC Plate Material in As-Received Condition. Etchant: 15% HF, 15% H_2SO_4, 8% HNO_3, 62% H_2O. 100X

TABLE 3

Room Temperature Properties of TZC Material

Heat	Condition	Ultimate Tensile Strength Ksi ($6.90 \times 10^6 N/m^2$)	0.2% Yield Strength Ksi ($6.90 \times 10^6 N/m^2$)	% Elongation 2" G.L.	% Reduction in area
M-91	as-received	124.7	111.6	1.4	0.8
M-80*	anneal, 1700°C-1 Hour	68.6	68.5	0.05	0
M-91	anneal, 1700°C-1 Hour	88.2	47.8	9.0	8.0

Specimen orientation: Tensile axis transverse to rolling direction

Strain rate = 0.005"/"/min

* Possibility that brittle fracture occurred before conventional yielding.

creep test. The microstructures which result from the 3092°F (1700°C) annealing treatment are given in Figure 10. Complete recrystallization was produced in the Heat M-91 material while only partical recrystallization took place in the Heat M-80 which had a smaller degree of warm working during processing. As a result, the room temperature strength of the recrystallized Heat M-91 material after the annealing treatment was significantly less than that obtained in partially recrystallized Heat M-80.

The microstructures of the columbium alloy, AS-30 and Cb132M, in the as-received condition are shown in Figures 11 and 12. The AS-30 was tested in the as-received condition while the Cb132M was evaluated after annealing at 3092°F (1700°C) for one hour (see Figure 13). In this annealed condition, the Cb132M had the following room temperature properties:

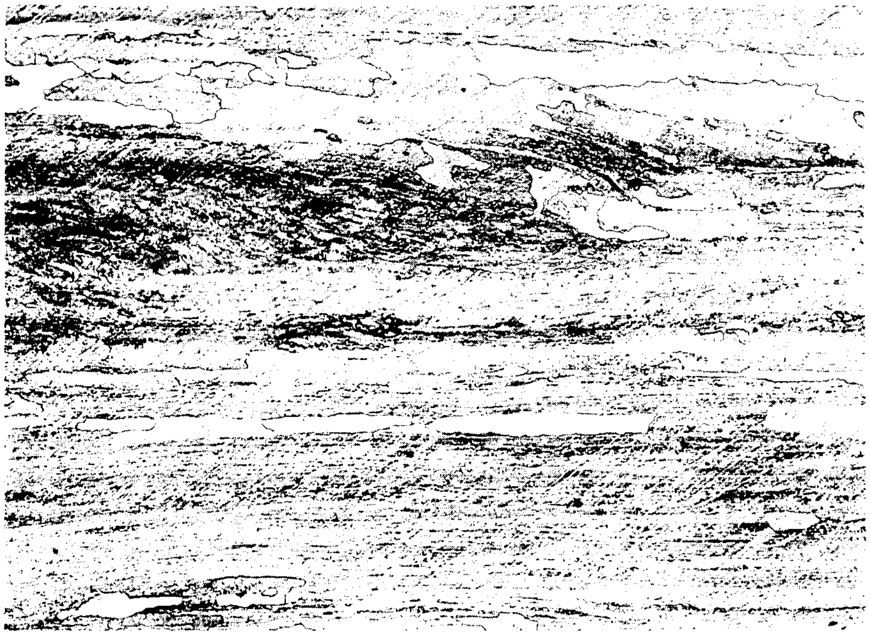
Tensile strength:	121.2 Ksi	($8.35 \times 10^8 N/m^2$)
0.2% Yield Strength:	109.8 Ksi	($7.55 \times 10^8 N/m^2$)
Reduction in area:	4%	

The T-222 and T-111 alloys are being tested as sheet material. Prior to evaluation, the T-222 alloy was recrystallized at 3000°F (1648°C) for one hour and representative photomicrographs of the as-received and recrystallized structure are presented in Figure 14. The microstructure of the T-111 material in the as-received condition and after recrystallizing at 2600°F (1426°C) for one hour are shown in Figure 15. The as-received T-111 showed a variation in hardness from the surface of the sheet to the center (339 DPH at surface to 230 DPH at center). Stringers were also present in the section near the surface (see Figure 15).

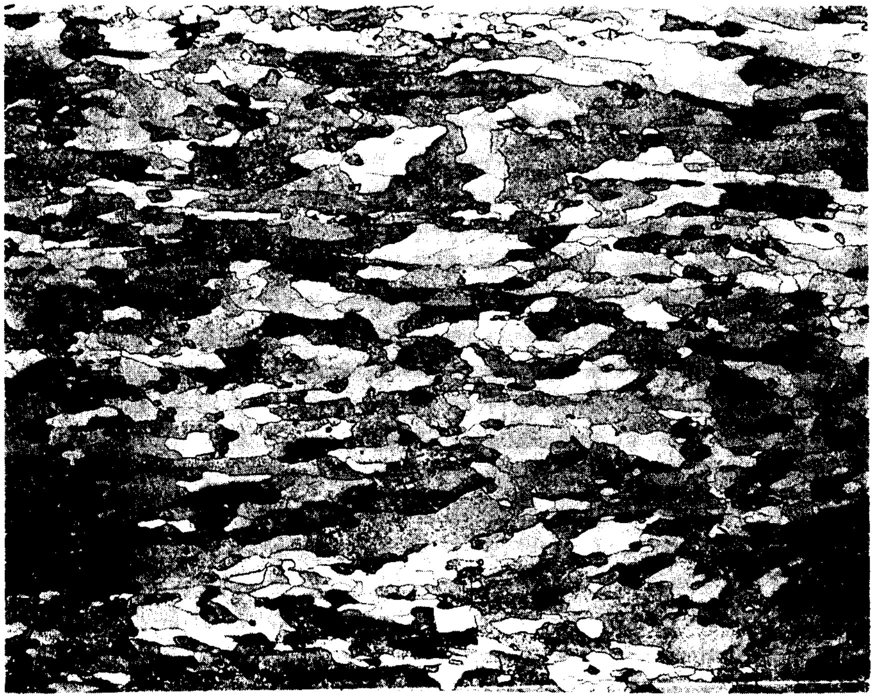
The orientation of the test specimens with reference to the processing conditions and their geometry are summarized in Appendix II. The TZM specimens machined from the forged discs were cut with the tensile axis parallel to the disc radius. The specimen taken from plate were oriented so that the tensile axis was transverse to the rolling direction while the axis of the sheet specimens was parallel to the rolling direction.

III. PROCEDURE

The operation of the test units has been described in detail in the fourth quarterly progress report. The test procedure involves obtaining a vacuum of 5×10^{-10} Torr or better at room temperature, then heating the specimen at a rate so that the pressure never rises above 1×10^{-6} Torr. The specimen is then held at temperature for approximately two hours prior to load application. After the first few minutes of loading, specimen contraction may be observed due to a slight temperature decrease produced

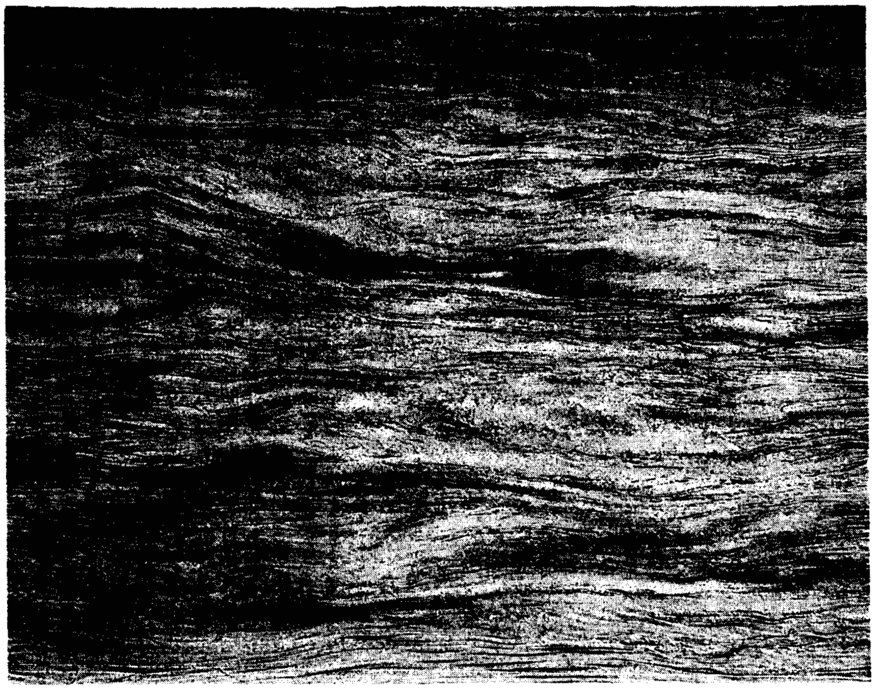


TZC Heat M-80



TZC Heat M-91

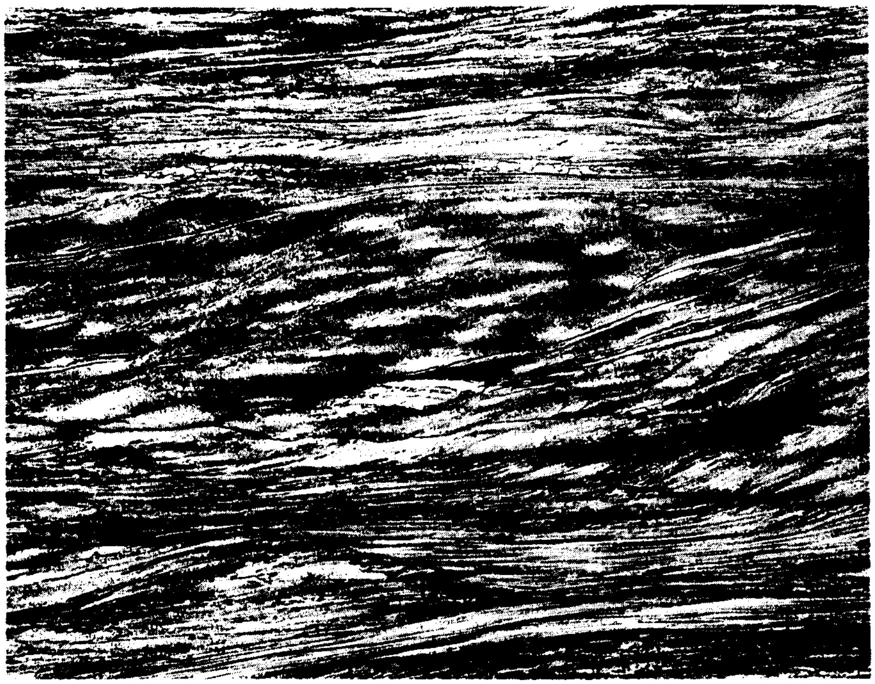
9271 **Figure 10.** Photomicrographs of TZC Plate After Annealing at 3092°F (1700°C) for 1 Hour, Etchant: 15% HF, 15% H_2SO_4, 8% HNO_3, 62% H_2O. 100X



Edge Parallel to Rolling Direction.

Surface of Plate.

Figure 11. Microstructure of AS-30 Plate in As-Received Condition. Etchant: 15% HF, 15% H_2SO_4, 8% HNO_3, 62% H_2O. 100X



Edge Parallel to Rolling Direction.

Surface of Plate.

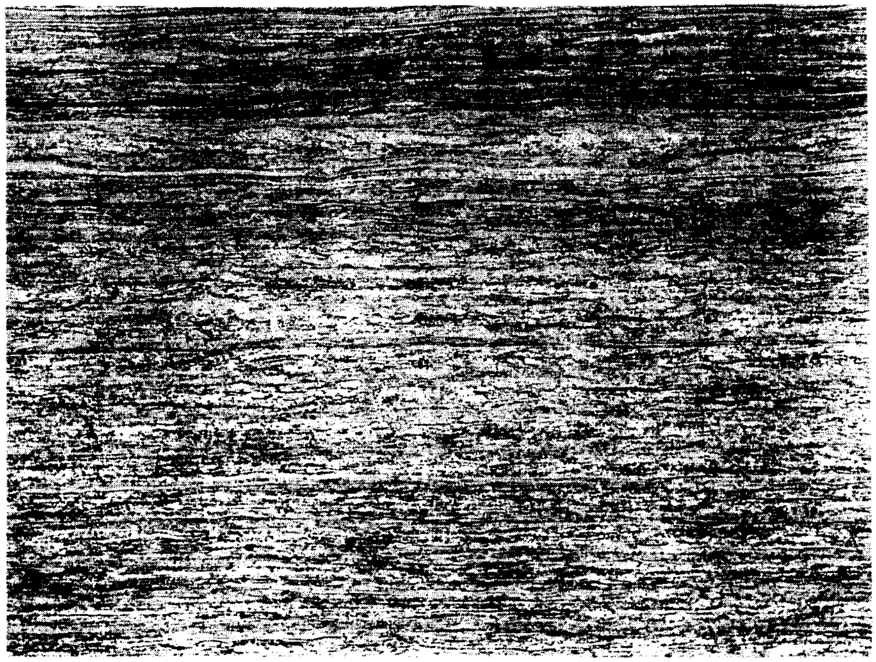
Figure 12. Microstructure of Cb-132M Plate in As-Received Condition.
Etchant: 15% HF, 15% H_2SO_4, 8% HNO_3, 62% H_2O. 100X

9278

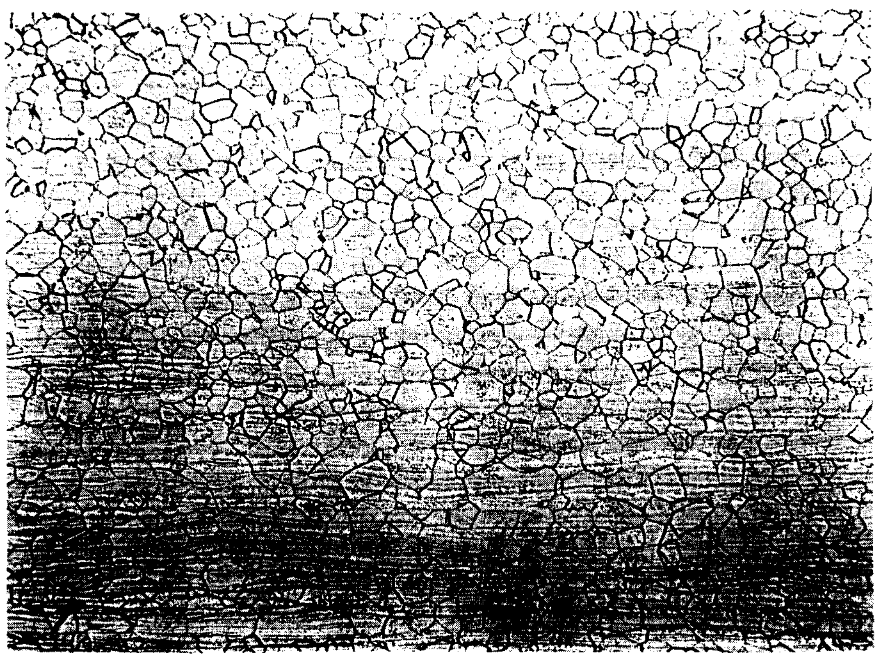
Edge Parallel to Rolling Direction.

Figure 13. Microstructure of Cb-132M Plate After Annealing at 3092°F (1700°C) for 1 Hour. Etchant: 15% HF, 15% H_2SO_4, 8% HNO_3, 62% H_2O. 100X

9275



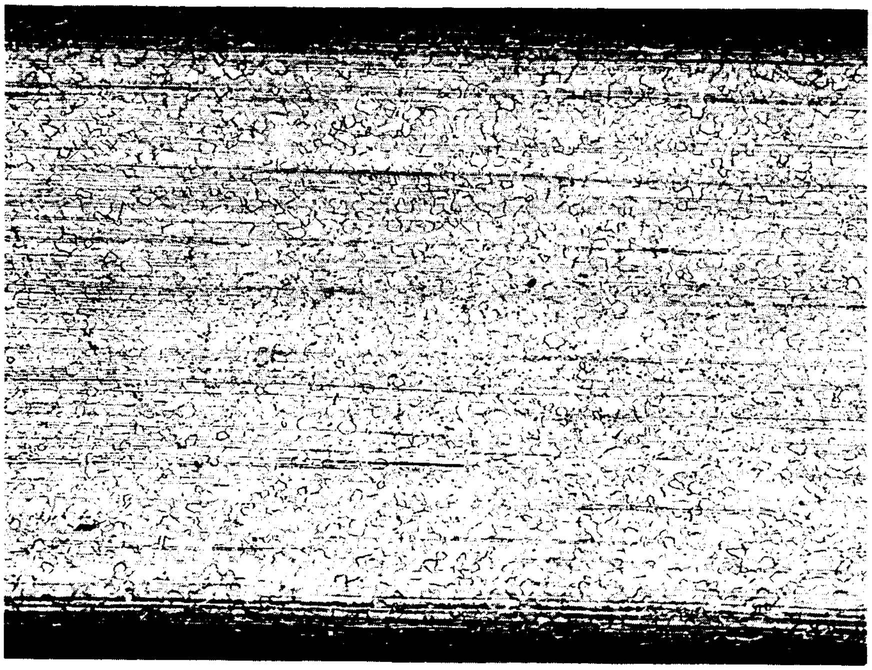
T-222 Sheet As-Received Condition.



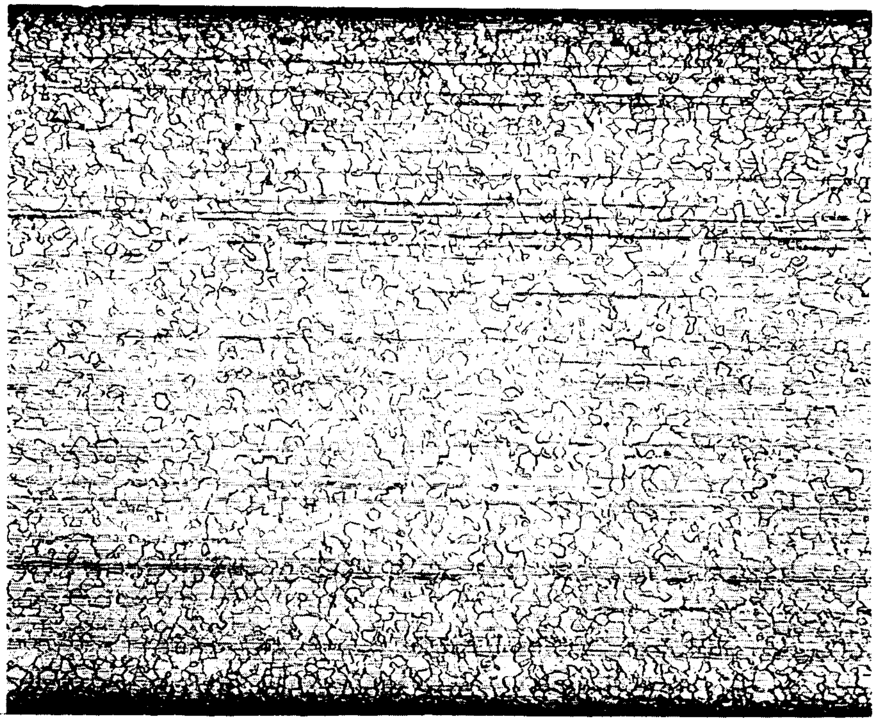
T-222 Sheet, Recrystallized 3000°F (1649°C) 1 Hour.

Figure 14. Microstructure of T-222 Sheet, Etchant: 15% HF, 15% H_2SO_4, 8% HNO_3, 62% H_2O. 100X

9274



T-111 Sheet, As-Received Condition.



T-111 Sheet, Recrystallized 2600°F (1426°C), 1 Hour.
Stringers are Present Near the Surface.

9270

Figure 15. Microstructures of T-111 Sheet. Etchant: 15% HF, 15% H_2SO_4, 8% HNO_3, 62% H_2O. 100X

by the increased grip contact and the resulting increase in heat conduction. As the test proceeded the vacuum continuously improves to the 10^{-9} to 10^{-10} Torr level.

The test temperature is initially set by a calibrated tungsten-3% rhenium vs. tungsten-25% rhenium thermocouple which in the case of bar specimens is attached by molybdenum wire to the gauge section of the specimen. In the case of sheet specimens the calibrated thermocouple is welded directly to the specimen just below the lower gauge mark. To compensate for possible drift in the thermocouple output during test, an optical brightness pyrometer capable of detecting a temperature change of 1°F is employed. As soon as the furnace is stabilized at the desired temperature, as indicated by the calibrated thermocouple, the optical pyrometer is focussed on the specimen and then on an argon-filled standard bulb inside the vacuum chamber. The lamp current is set so that it shows the same reading on the pyrometer as the test specimen. During the course of the test the temperature on the specimen is then maintained by adjusting , if necessary, the temperature controller to produce the same brightness as present on the standard lamp. In addition to maintaining a fixed test temperature, this technique has provided an indication of the drift in output of the tungsten-rhenium thermocouples as a function of the test time.

Specimen extension is measured over a 2 inch gauge length with an optical extensometer that determines the distance between two marks to an accuracy of $\pm 50\mu$-inches. The program plan involves testing the plate or forged alloys at temperatures between 1600 and 2250°F (871 and 1235°C)until a 1% total elongation is attained. The tungsten-base, sheet materials were tested at 3200°F (1760°C) for total extensions between 3 and 5% while the T-222 sheet materials are being evaluated in the 2000 to 2200°F (1093 to 1240°C) range to an elongation of approximately 2%. The applied stress levels were selected with the goal of obtaining creep data over total test times between 1000 and 10,000 hours.

IV. RESULTS AND DISCUSSION

In this section creep data are graphically presented as per cent elongation of the 2 inch gauge section as a function of the time at the applied stress. Reference marks indicating the chamber pressure during the test period are also placed on the curves. The specific data for each test which is in progress or completed during this test period are given in detail in Appendix III.

1. Tungsten-Base Alloys

The creep characteristics of the tungsten, tungsten-25% rhenium, and Sylvania A alloys at 3200°F (1760°C) are presented in Figures 16 through 19. Comparison of these data shows that at the higher stress levels the Sylvania A alloy possesses the greatest resistance to creep. The test series shown in Figure 16 for tungsten-25% rhenium at 5000 psi ($3.45 \times 10^7 N/m^2$) and W at 3000 psi ($2.07 \times 10^7 N/m^2$) indicates that tungsten-25% rhenium has creep resistance which is superior to tungsten. However, longer time tests conducted at lower stresses, did not show a significant difference between the two materials. A direct comparison of arc-melted and vapor-deposited tungsten tested at 1000 psi ($6.90 \times 10^6 N/m^2$) shown in Figure 18, indicates that the vapor-deposited material has slightly greater creep resistance. A comparison of the tungsten-base alloys using a Larson-Miller plot with a constant of 15 is given in Figure 20 along with data reported in the literature for short-time tests on tungsten consolidated by powder metallurgy methods and tested in an argon environment.

Although a critical evaluation of the influence of processing history or test environemtn on creep strength cannot be performed, since literature results were obtained in relatively short-time tests, the data do indicate a difference in creep properties which can be encountered in the tungsten-base alloys.

Typical microstructures of the tungsten-base alloys after various test times are shown in Figures 21 to 23. Appreciable grain growth occurred in the arc-melted materials during testing with the most pronounced example being the arc-cast tungsten tested for 3886 hours at 3200°C (1760°C) (see Figure 22). In contrast to the arc-cast alloys, the Sylvania A exhibited relatively little grain growth during testing (Figure 23).

2. Molybdenum-Base Alloys

The creep data for the TZM molybdenum alloy from Heat 7502 are shown in Figure 24 where a comparison is made between the material in the annealed and stress-relieved condition. The annealed material exhibits the greater degree of total creep extension primarily as a result of the rapid and discontinuous type of creep which occurred at approximately 500 hours. Additional discussion of the nature of the creep curves obtained in the annealed molybdenum alloys will be presented along with the data for the TZC material. TZM specimens from Heat 1175 are currently being

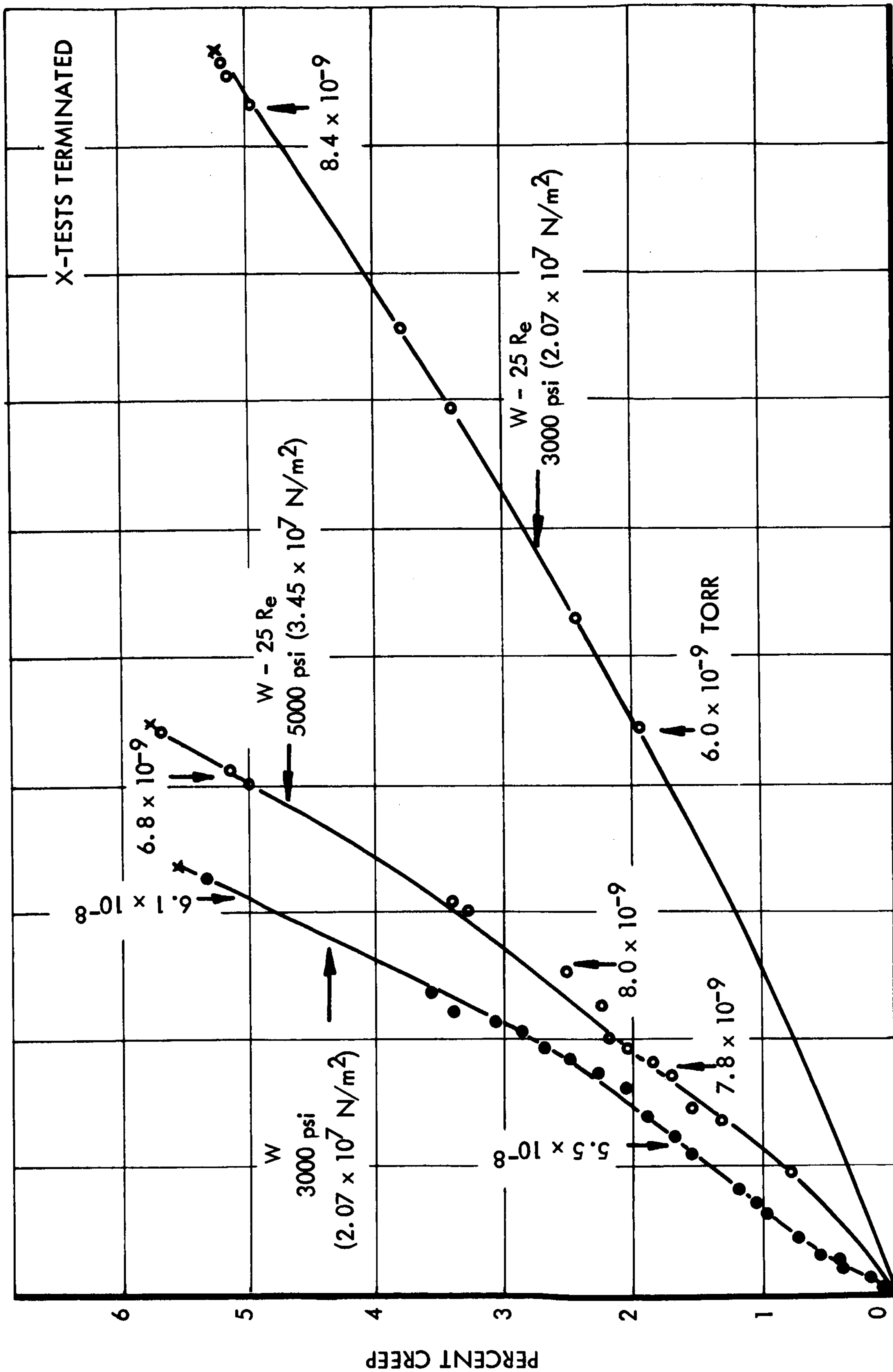


FIGURE 16. CREEP DATA FOR ARC-CAST TUNGSTEN AND TUNGSTEN-25% RHENIUM, RECRYSTALLIZED AT 3200°F (1760°C), TESTED AT 3200°F (1760°C), VACUUM ENVIRONMENT

9961

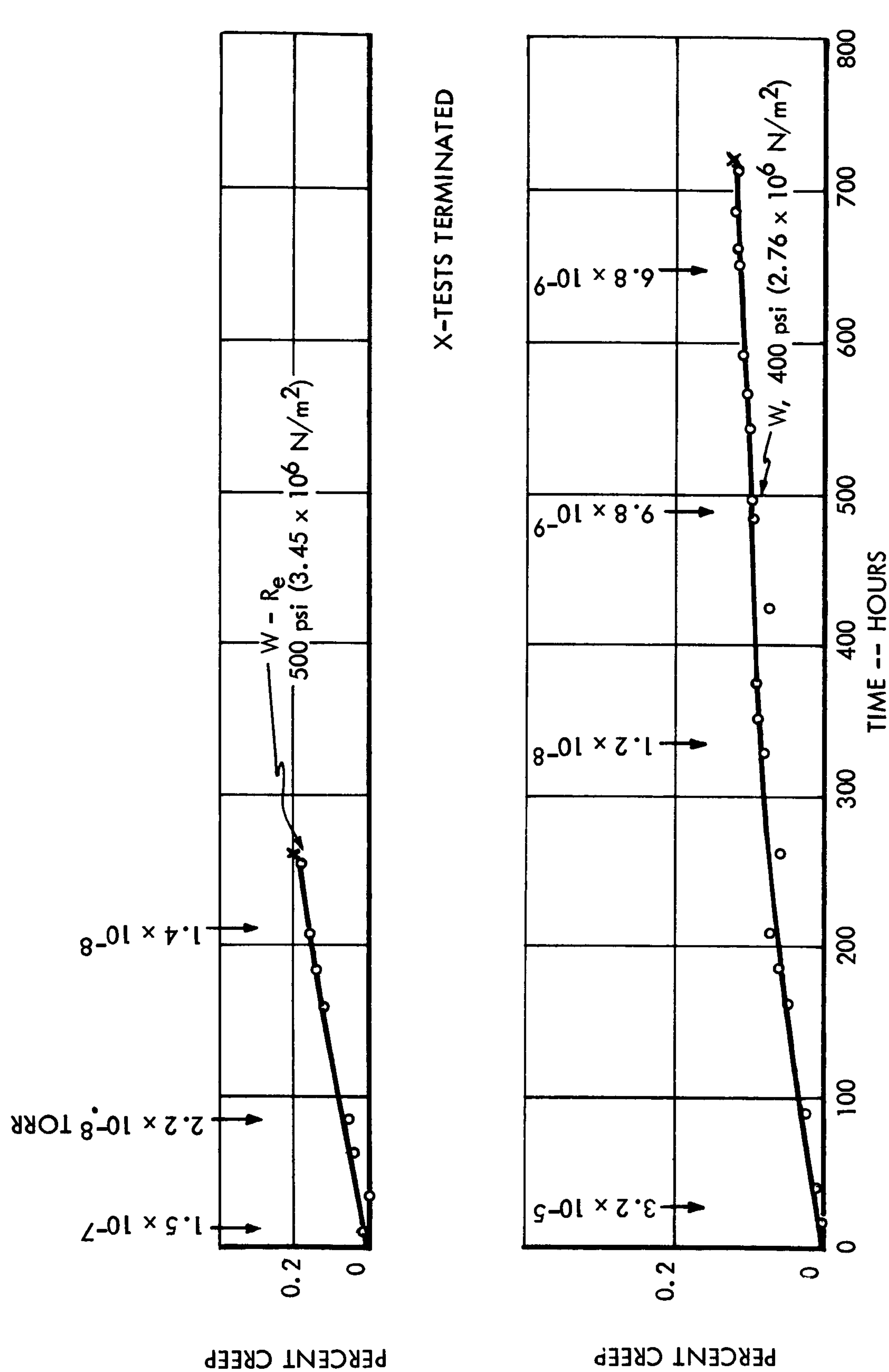


FIGURE 17. CREEP DATA FOR ARC-CAST TUNGSTEN AND TUNGSTEN-25% RHENIUM, RECRYSTALLIZED AT 3200°F (1700°C), TESTED AT 3200°F (1760°C) IN VACUUM ENVIRONMENT

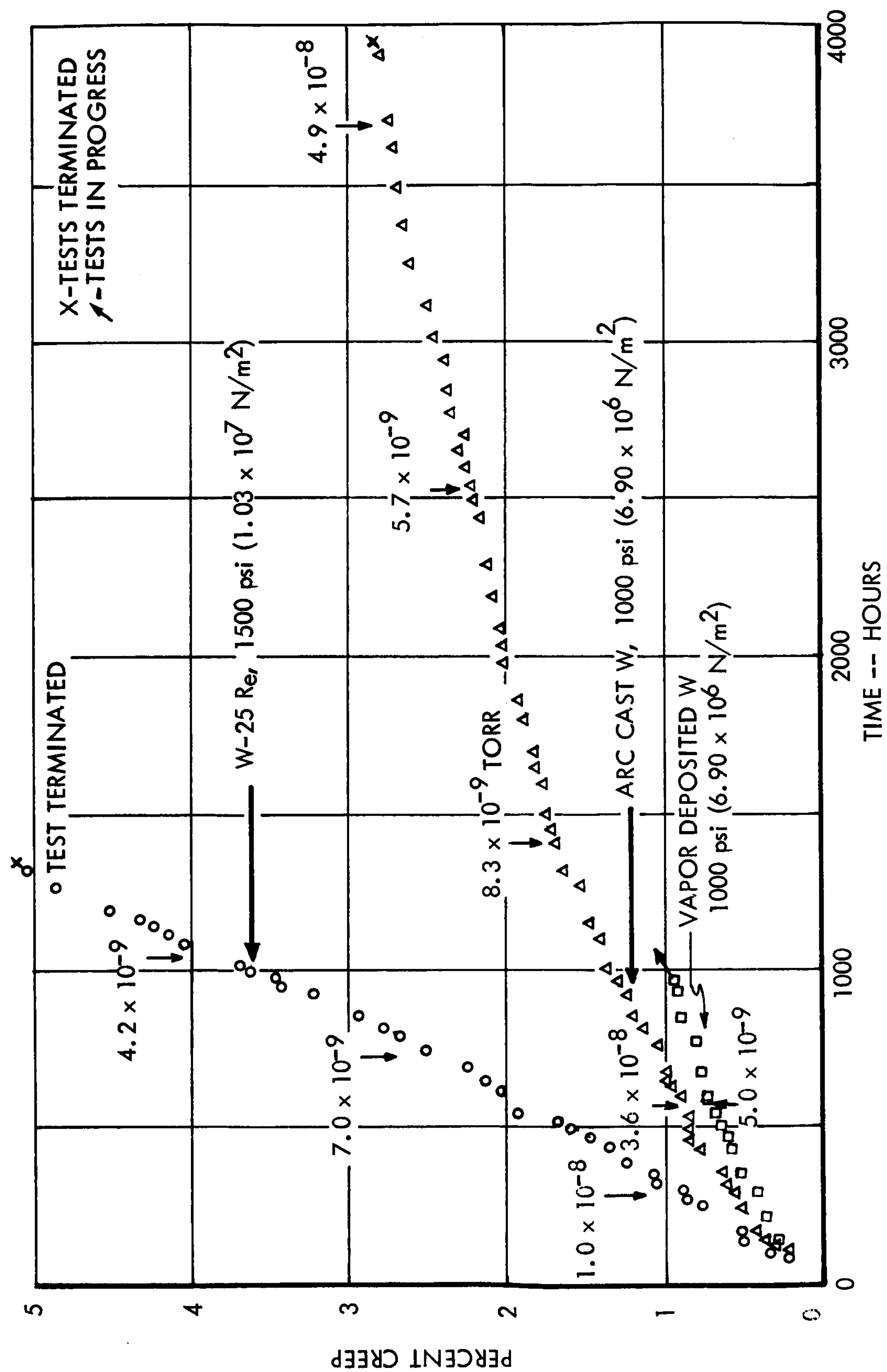


FIGURE 18. CREEP DATA FOR TUNGSTEN AND TUNGSTEN-25% RHENIUM, RECRYSTALLIZED AT 3200°F (1760°C), TESTED AT 3200°F (1760°C) IN VACUUM ENVIRONMENT

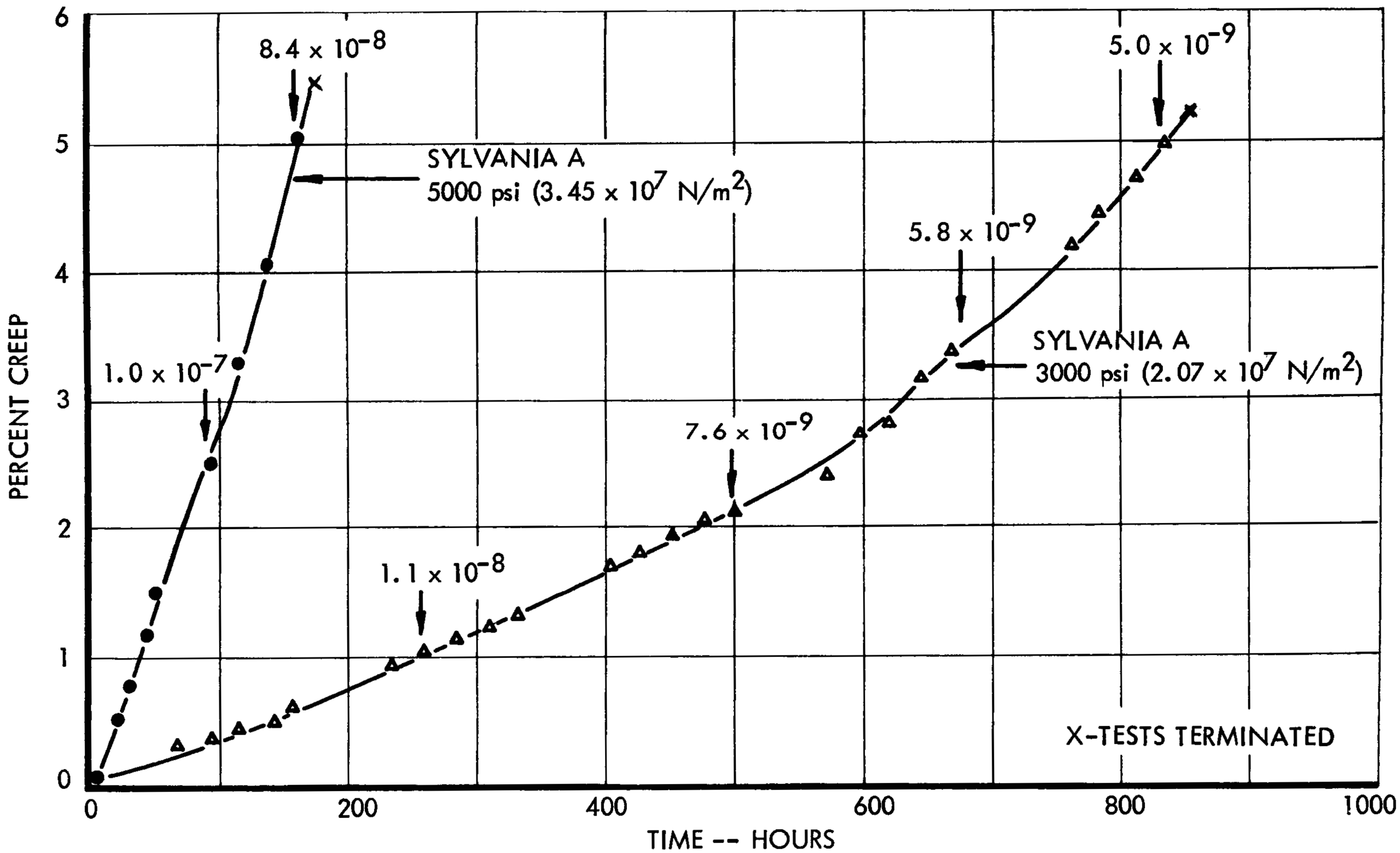


FIGURE 19. CREEP DATA FOR SYLVANIA A, RECRYSTALLIZED AT 3200° F (1760° C), TESTED AT 3200° F, VACUUM ENVIRONMENT

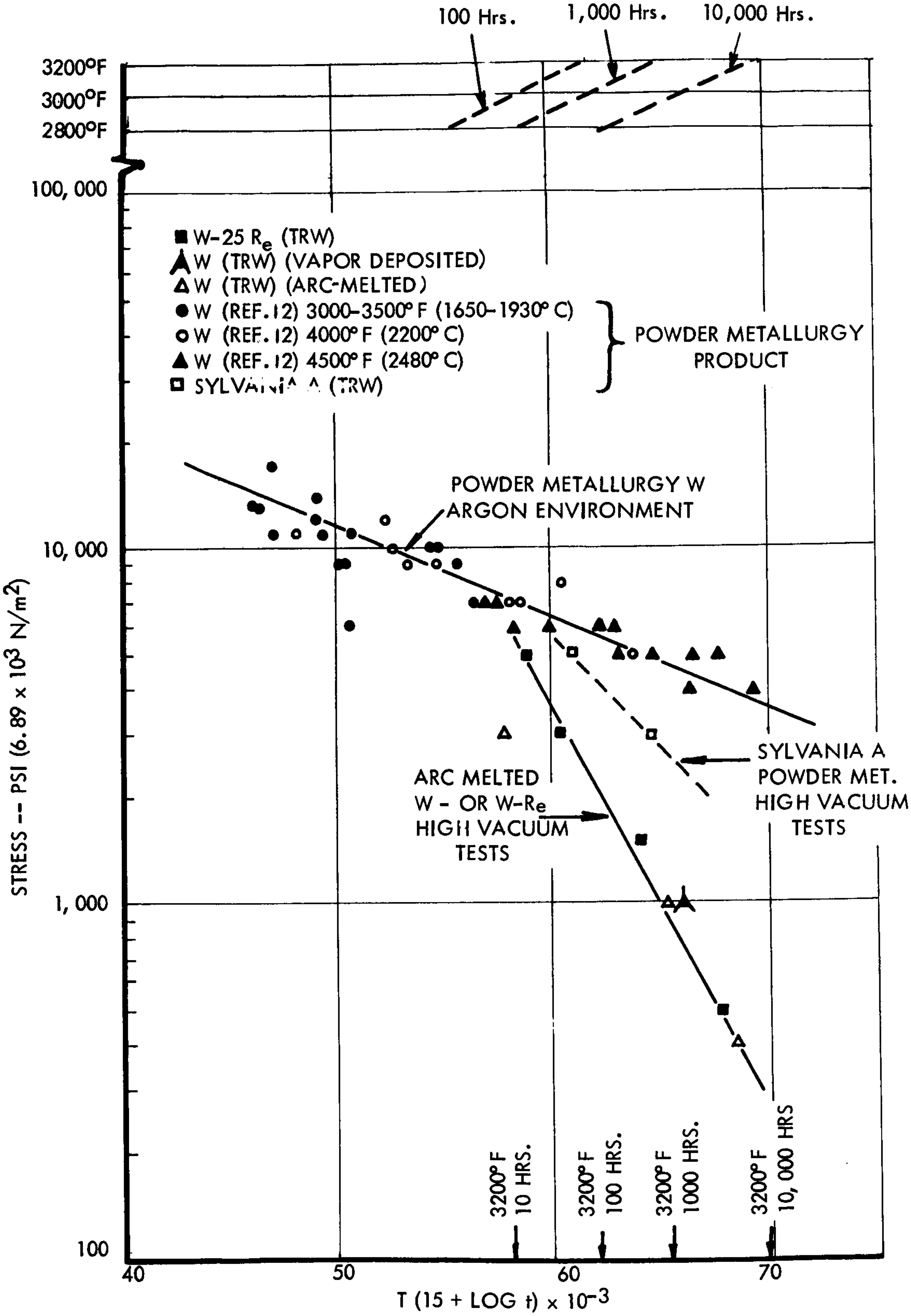
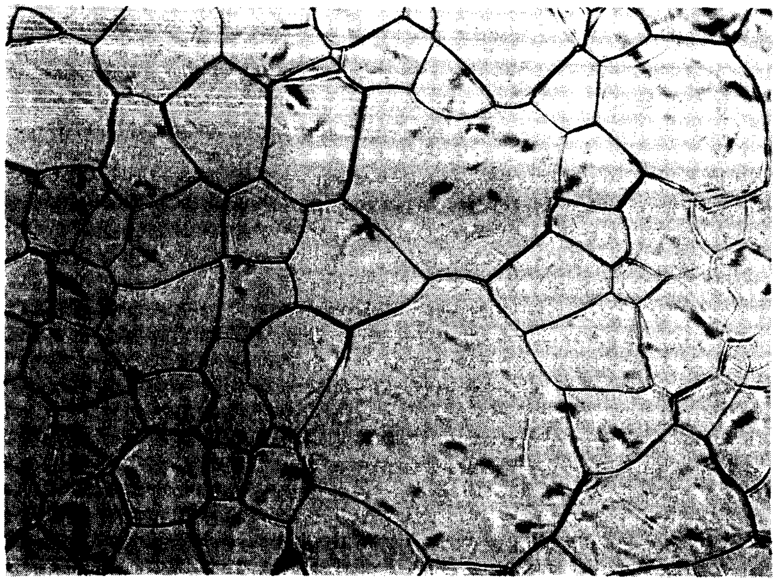
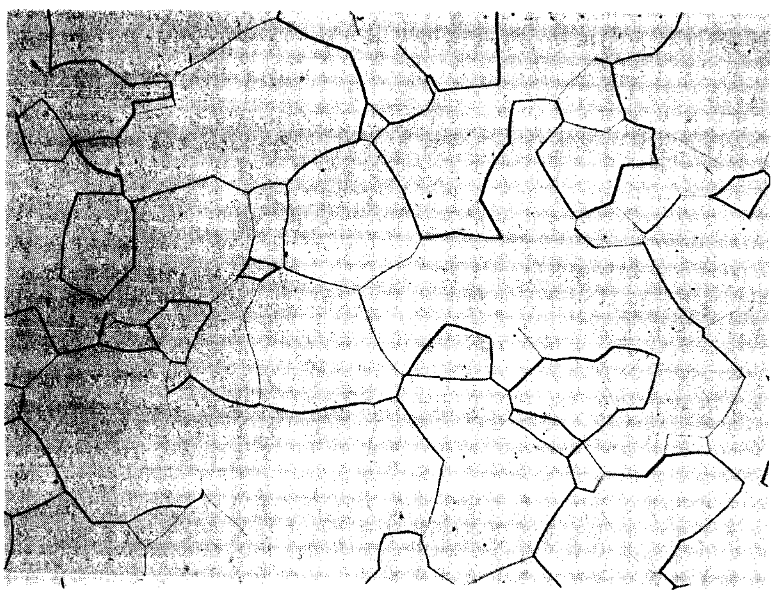


FIGURE 20. LARSON-MILLER PLOT OF TUNGSTEN AND TUNGSTEN-25% RHENIUM 1% CREEP DATA, (T = TEST TEMPERATURE °R, t = TEST TIME, HOURS)

9976



Unpolished Surface of Specimen Showing Thermal Etching.



Typical Microstructure After Polish and Etch.
Etchant: 15% HF, 15% H_2SO_4, 8% HNO_3, 62% H_2O.

Figure 21. Microstructures of Tungsten-25% Rhenium Alloy After Testing at 3200°F for 97 Hours. 100X

Figure 22. Microstructure of Cross-Section of Tungsten Sheet After Testing at 3200°F, 3886 Hours. Etchant: 15% HF, 15% H_2SO_4, 8% HNO_3, 62% H_2O. 100X

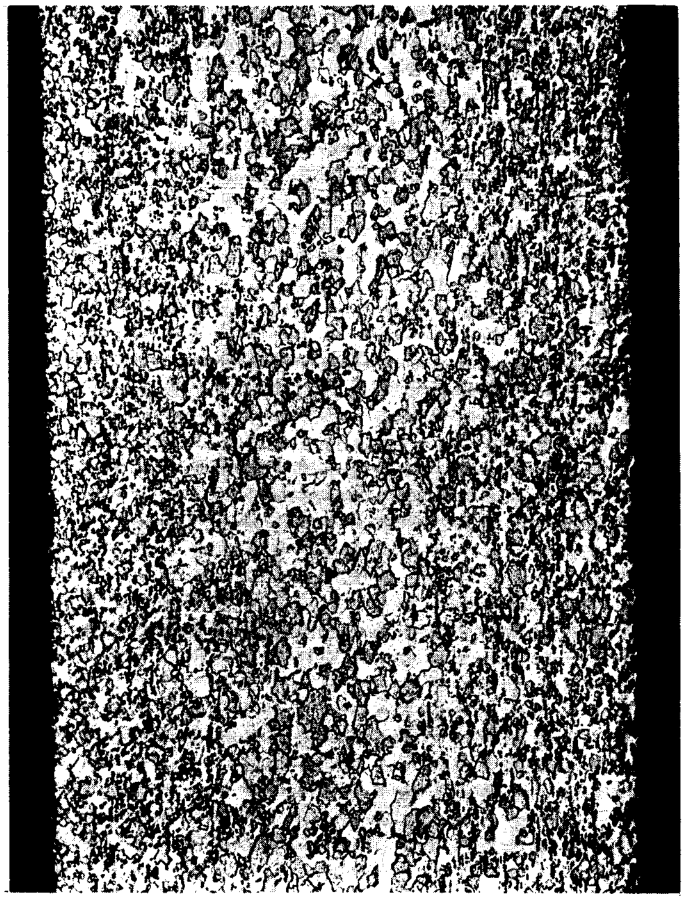


Figure 23. Microstructure of Cross-Section of Sylvania A Sheet After Testing at 3200°F, 967 Hours. Etchant: 15% HF, 15% H_2SO_4, 8% HNO_3, 62% H_2O. 100X

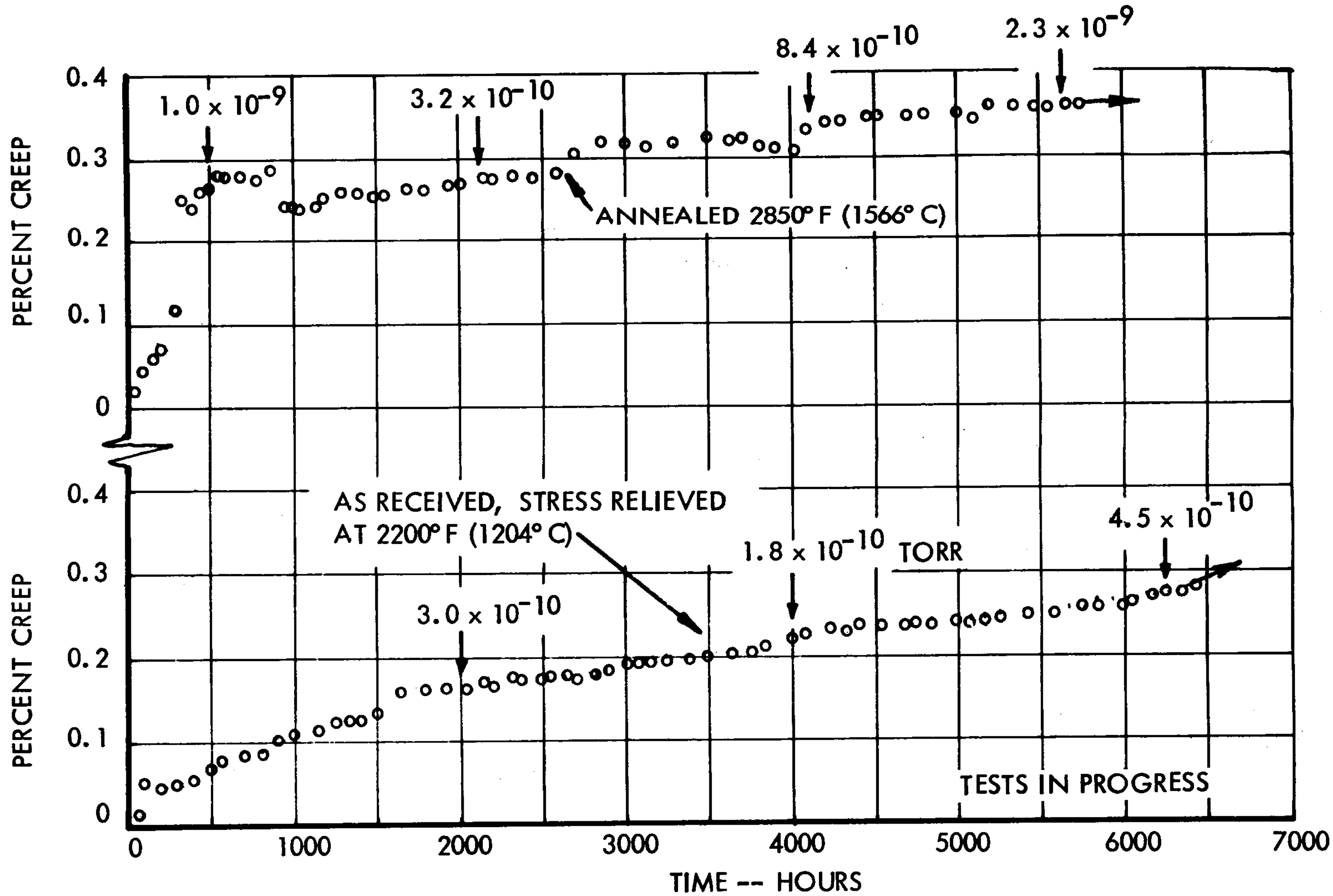


FIGURE 24. CREEP DATA FOR TZM DISC FORGINGS, (HEAT 7502), TESTED AT 2000° F (1093° C) 10 KSI (6.90×10^{7} N/m^2) IN VACUUM ENVIRONMENT

9957

tested and the data are summarized in Table 4. At present only relatively small amounts of extension have been recorded and no anamolies have been noted in the creep curves.

Table 4

Creep Data for TZM Alloy, Heat 1175

Stress-Relieved Condition, 2300°F (1260°C), 1 Hour

Applied Stress Ksi ($6.90 \times 10^6 N/m^2$)	Test Temperature °F	°C	Total Test Time (Hours)	Total Extension %
55	1600	871	718	0.017
24	1856	1013	2489	0.032

The creep extension measured on the TZC alloy (Heat M-80) is shown in Figures 25 and 26. The creep curves exhibit a considerable number of discontinuties and in fact the specimen tested at 2056°F (1124°C) actually is undergoing "negative" creep after approximately 3000 hours. The creep curves show that rapid increases in creep are generally followed by extended periods where virtually no creep extension is apparent. The TZC alloy is susceptible to strain-induced precipitation (2,3) and the discontinuities in the creep curve can be qualitatively rationalized on the basis of this phenomenon. The presence of local deformation during the test provides the sites for the formation of the strain-induced precipitate which could temporarily inhibit further creep. These barriers are eventually overcome leading to a continued sequence of deformation and additional precipitation. The TZC alloy undergoes substantial hardening during the test which further indicates that precipitation is occurring (e.g. 256DPH to 350DPH after 1197 hours at 2200°F (1204°C). Photomicrographs at 100X (see Figure 27) fail to indicate the presence of a fine precipitate, which appears as a second phase in the electron micrographs shown in Figure 28. The exposure of the specimen to the test condition has produced a marked subgrain network and an increase in quantity of precipitate.

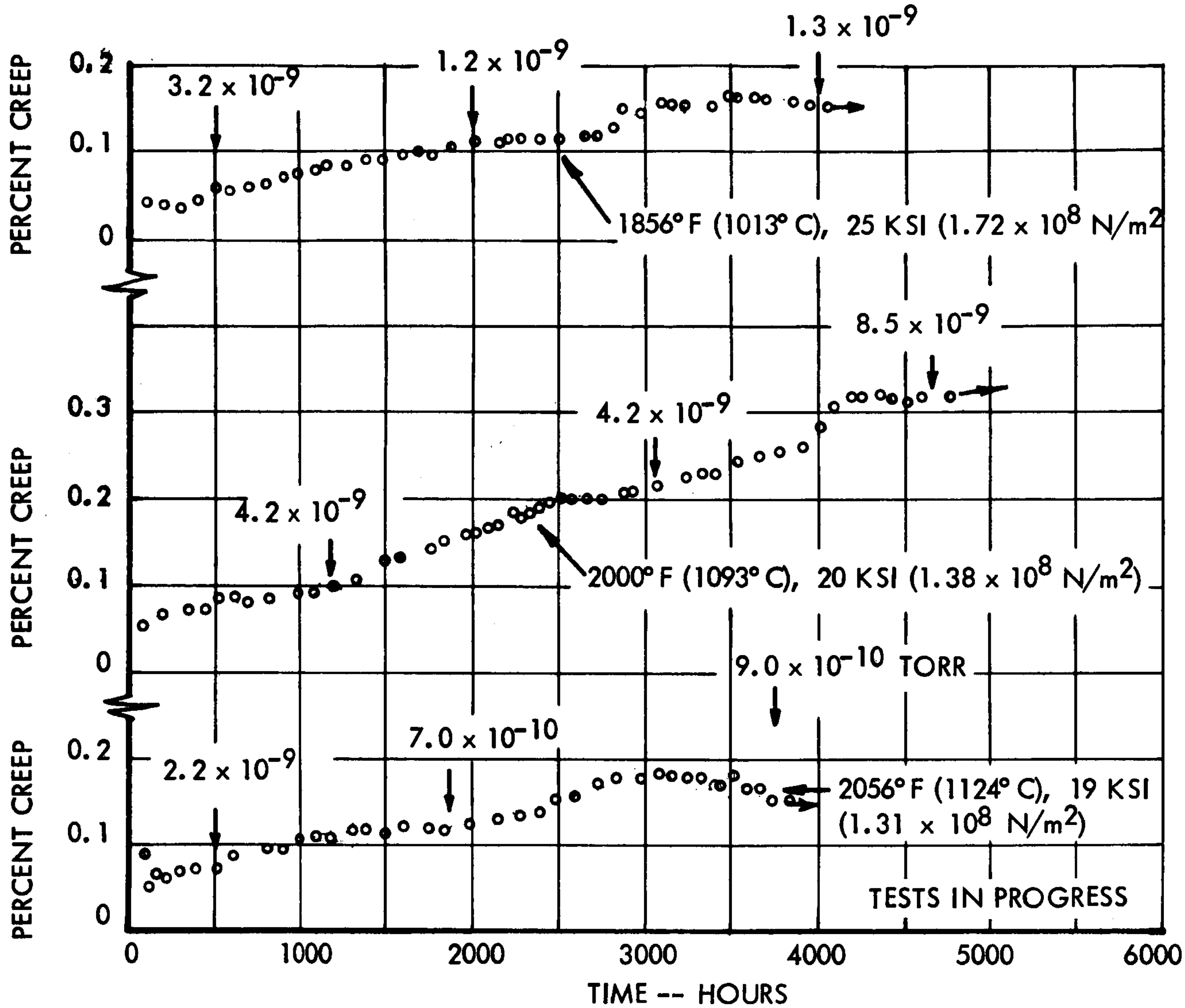


FIGURE 25. CREEP DATA FOR TZC PLATE (HEAT M-80) ANNEALED AT 3092° F (1700° C), TESTED IN VACUUM ENVIRONMENT

9956

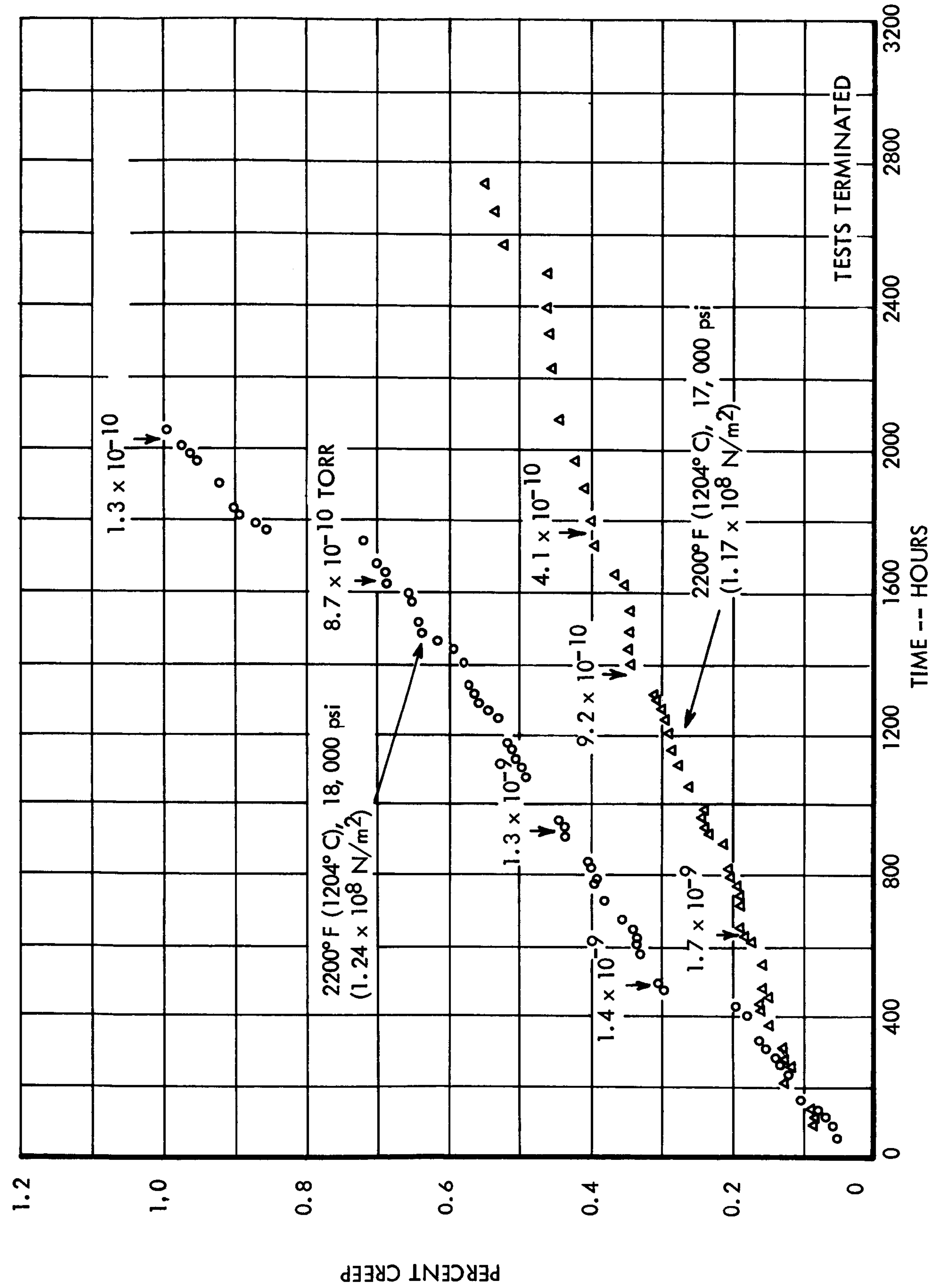


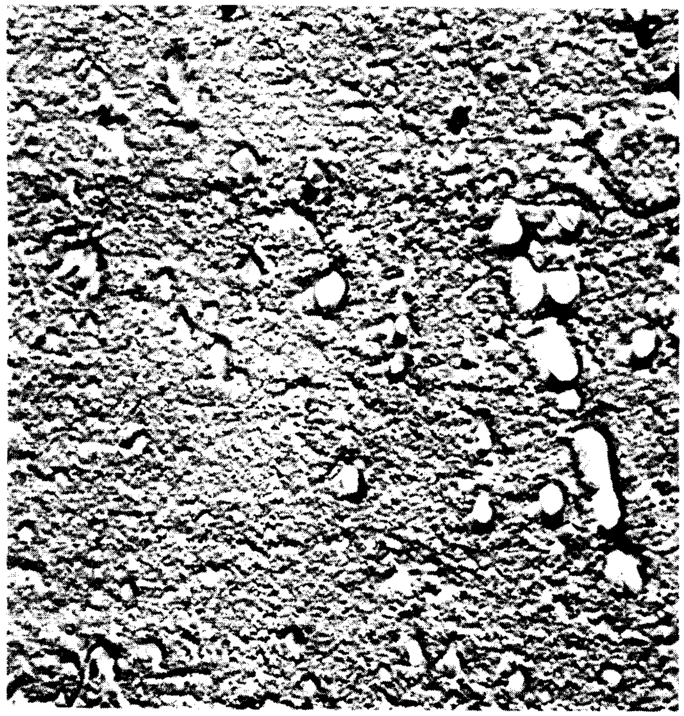
FIGURE 26. CREEP DATA FOR TZC PLATE (HEAT M-80) ANNEALED AT 3092°F (1700°C), TESTED IN VACUUM ENVIRONMENT

9958

Structure After Annealing at 1700°C for 1 Hour,
Hardness 256 DPH.

Structure After Annealing at 1700°C for 1 Hour
and Testing for 1196 Hours at 1094°C (2000°F),
Hardness 350 DPH.

Figure 27. Structure of TZC Alloy (Heat M-80) After Annealing and After Testing. Etchant: 15% HF, 15% H_2SO_4, 8% HNO_3, 62% H_2O. 100X



A. TZC Alloy Heat M-80, Annealed 3092°F, 1 Hour.

B. TZC Alloy Heat M-80, Annealed 3092°F, 1 Hour, Tested at 2000°F, 2130 Hours, 18 ksi.

Figure 28. Electron Micrographs of TZC Alloy Before and After Creep Testing, 10,000X.

9279

"Negative" creep and discontinuities in the creep curve have been observed in numerous commercial alloys (4, 5, 6, 7) and in all cases the phenomenon can be associated with a phase change or a precipitate which produces an increase in volume of the alloy being tested. Although difficult to accurately define, "negative" creep is observed in the annealed TZC alloy after approximately 3000 hours at 2056°F (1124°C) test and after 3750 hours in the 1856°F test. At present, sufficient data are not available to define the kinetics governing the formation of the strain-induced precipitate.

Creep tests have recently been initiated on specimens of TZC from Heat M-91. Current results on a specimen in the stress-relieved condition (2300°F, 1260°C) indicate a total extension of 0.190% after 140 hours at 1800°F (982°C) with an applied stress of 44 ksi ($3.03 \times 10^7 N/m^2$).

3. Columbium and Tantalum Base Alloys

The creep curves for AS-30 and Cb132M at three test conditions are presented in Figures 29 through 31. The Cb132M exhibits creep resistance superior to the AS-30 over the test conditions evaluated (see Figure 32). The AS-30 exhibited a slight decrease in hardness as a result of the exposure during testing with the greatest change taking place after testing for 1193 hours at 2000°F (1093°C) (293 DPH to 268 DPH). Although the Cb132M alloy is susceptible to strain-induced precipitation (8) no significant variation in structure or hardness was produced as a result of creep testing the alloy in the 3092°F (1700°C) annealed condition.

Tests are being conducted on the T-222 alloy in sheet form and the currently-available results are presented in Figure 33. The characteristics of the creep curves were somewhat unique in that the creep rate continuously increased during the course of the test.

4. Comparative Creep Properties

In rotating systems the strength-to-weight ratio represents the critical parameter for comparing relative material performance. Although in many cases testing has not been completed to the extent that 1% creep values have been obtained, it is informative to compare the classes of alloys on the basis of the available data to obtain relative performance ratings. Figure 34 presents results for T-222, Cb132M, TZC, and TZM, which has been normalized to allow comparison on a comparable stress-to-weight basis. The AS-30 alloy has not been included since it has creep resistance which is inferior to Cb132M. The pertinent data used to compile Figure 34 are summarized in Table 5. In cases where extension to 0.5 or 1.0% creep had not been attained, but sufficient data were available to define the curve,

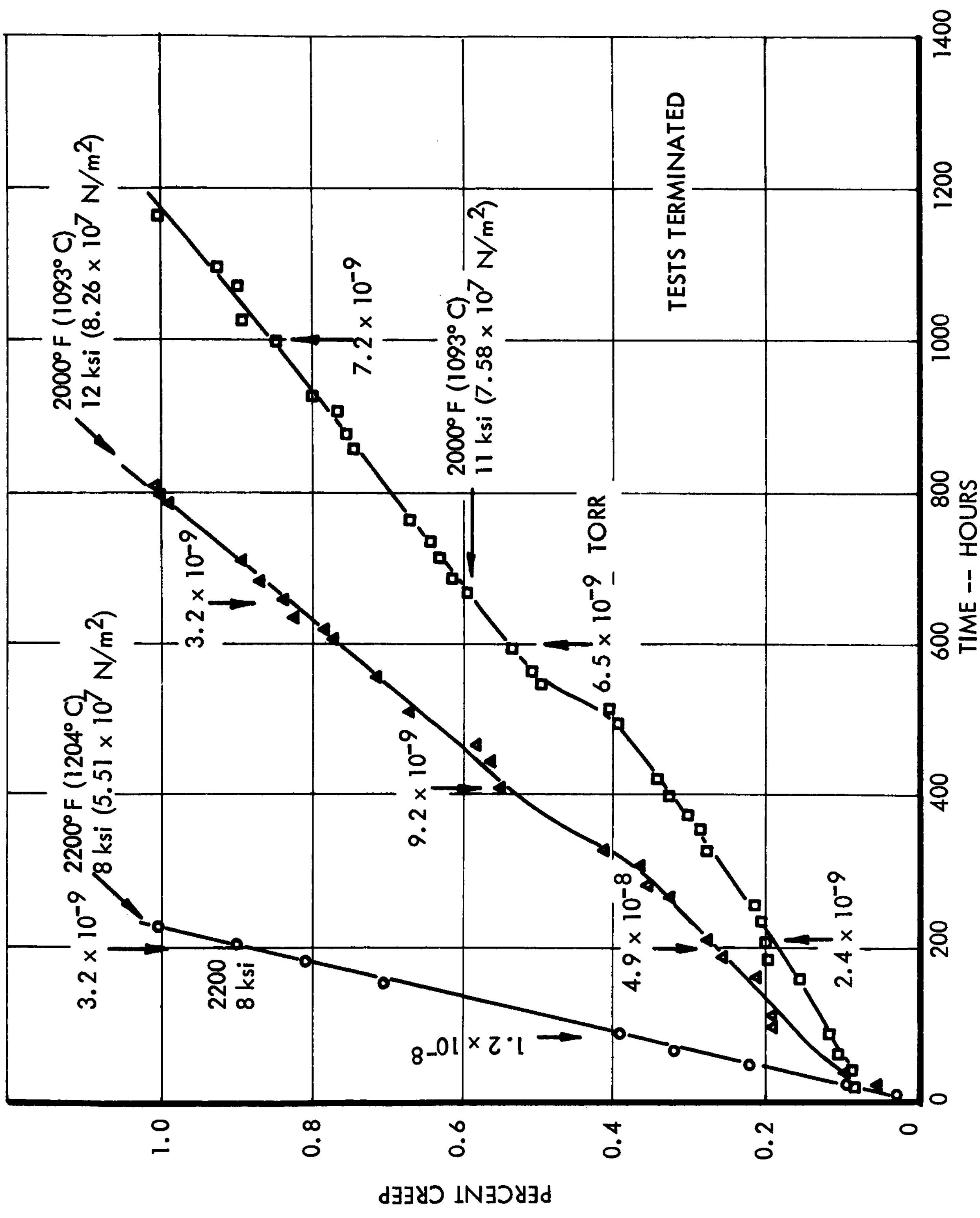


FIGURE 29. CREEP DATA FOR AS-30 ALLOY, VACUUM ENVIRONMENT

9959

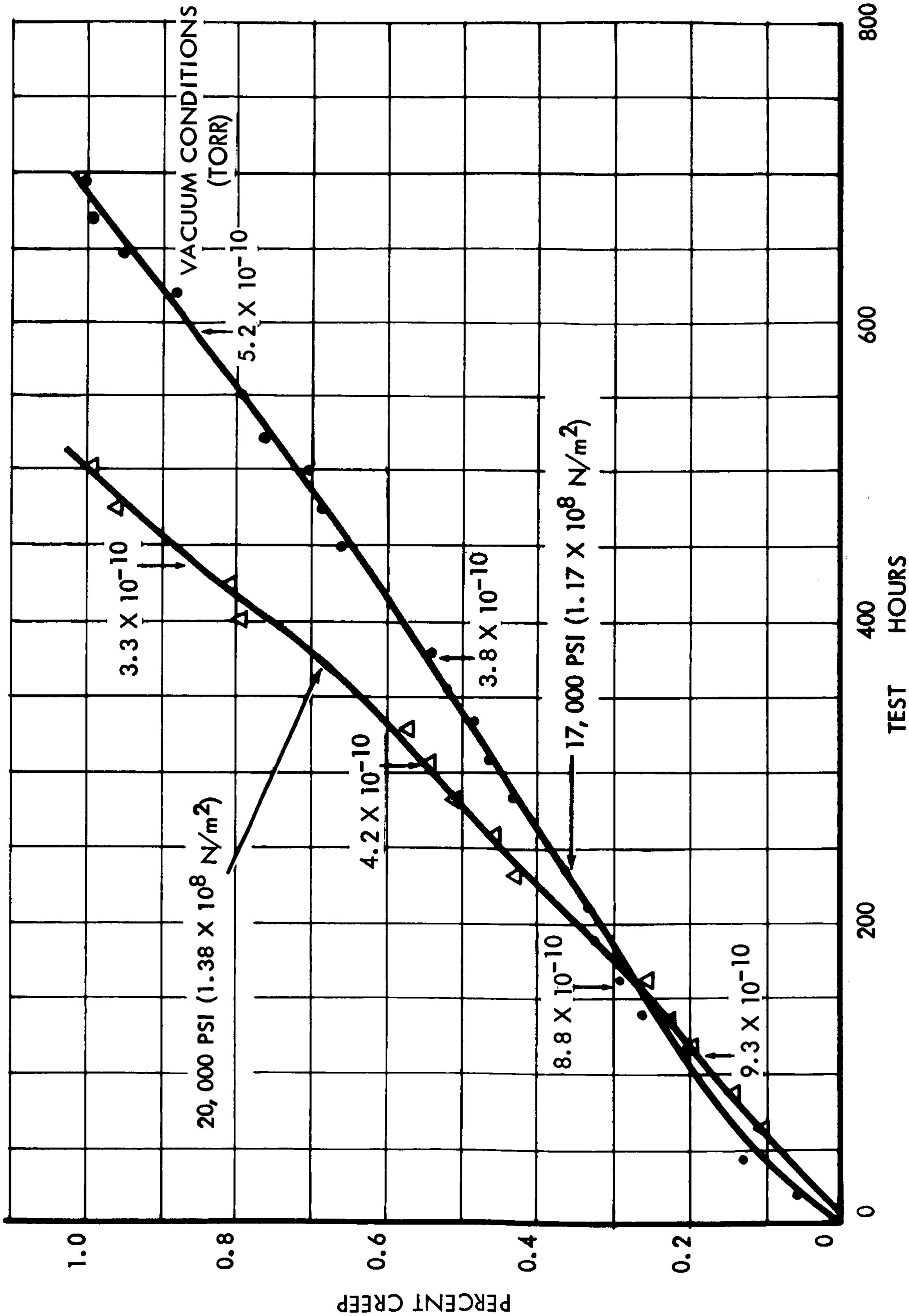


Figure 30. Creep Data for Cb-132M Annealed at 3092°F (1700°C) for 1 Hour, Tested at 2056°F (1124°C) in Vacuum Environment.

9735

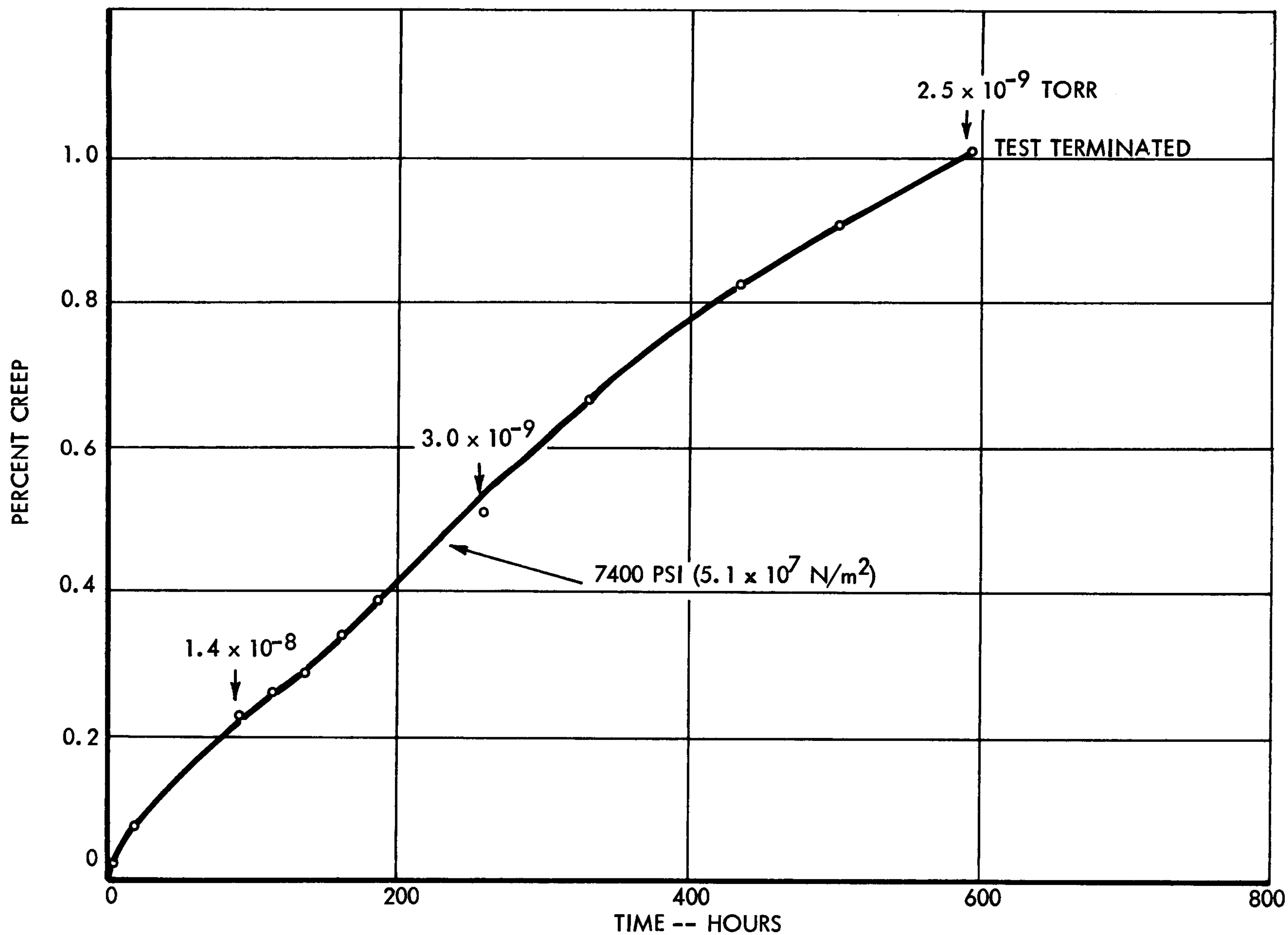


FIGURE 31. CREEP DATA FOR Cb 132M ANNEALED AT 3092°F (1700°C) FOR ONE HOUR, TESTED AT 2256°F (1332°C) IN VACUUM ENVIRONMENT

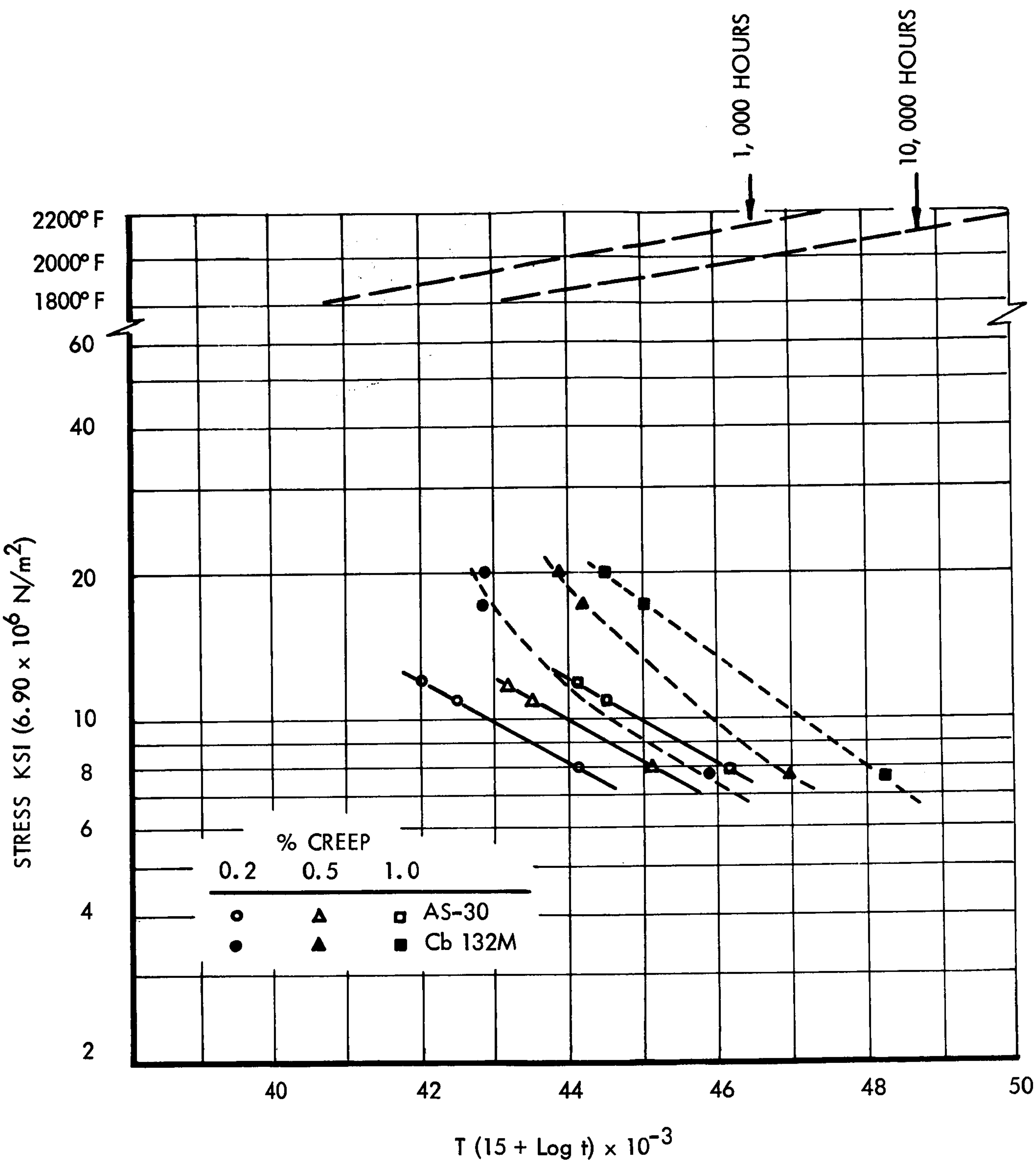


FIGURE 32. LARSON-MILLER PLOT OF CREEP DATA FOR AS-30 AND Cb 132M ALLOYS

9963

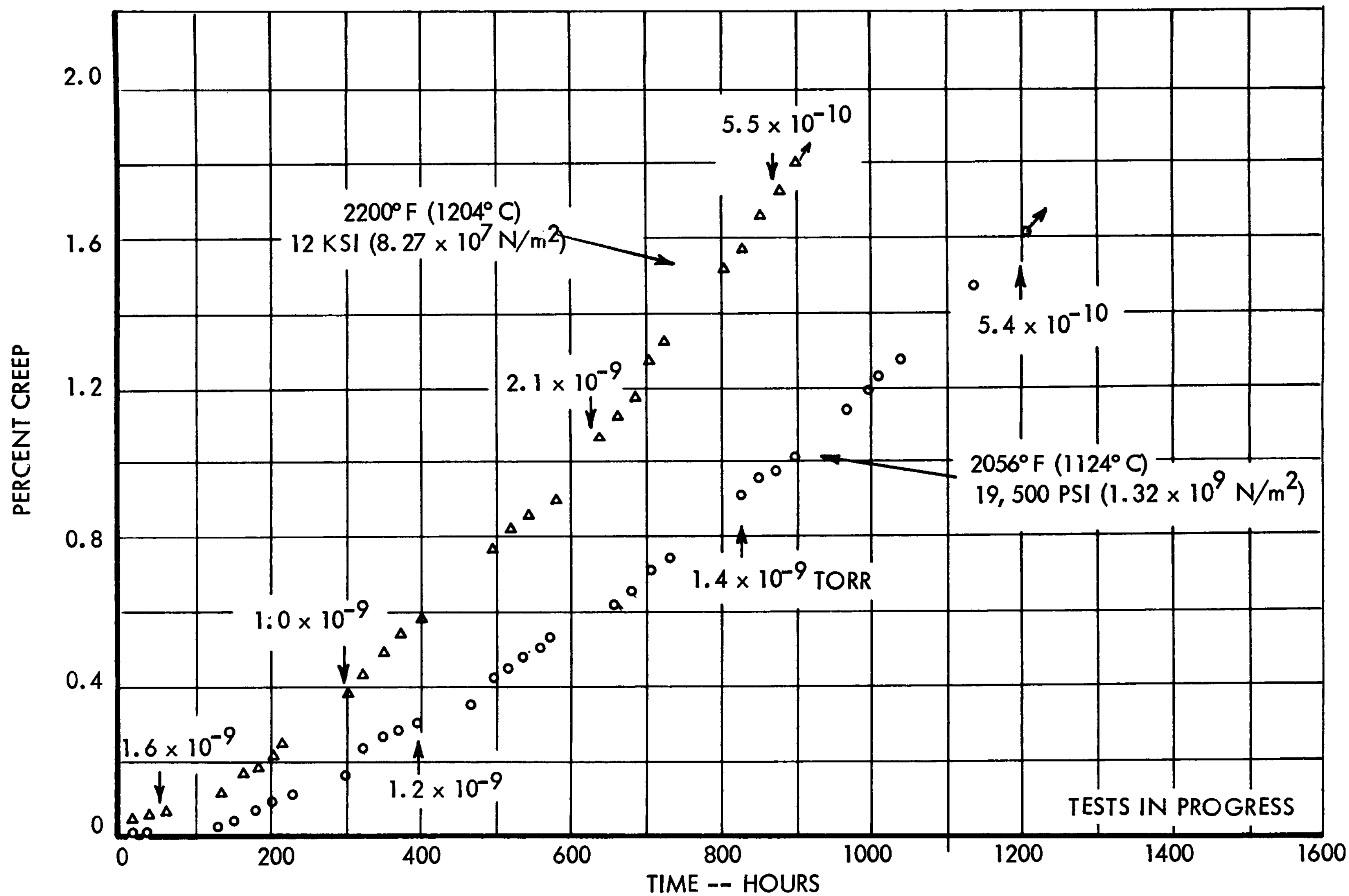


FIGURE 33. CREEP DATA FOR T-222 ALLOY, ANNEALED AT 3000° F (1649° C) FOR ONE HOUR, TESTED IN VACUUM ENVIRONMENT

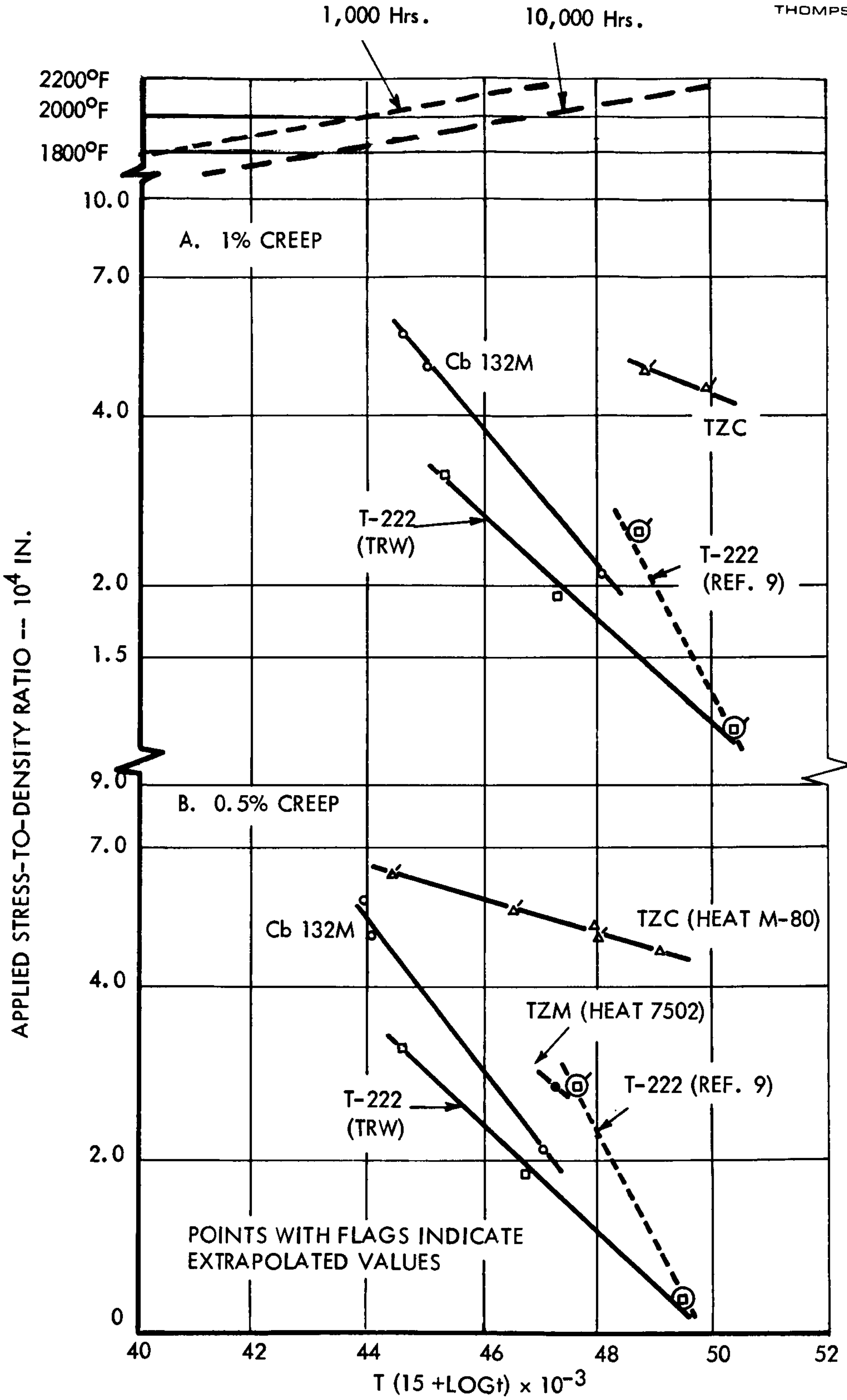


FIGURE 34. LARSON-MILLER PLOT OF CREEP DATA FOR A VARIETY OF HIGH STRENGTH REFRACTORY ALLOYS TESTED IN ULTRA HIGH VACUUM ENVIRONMENT. APPLIED STRESS IS EXPRESSED IN TERMS OF STRENGTH-TO-DENSITY RATIO

9977

TABLE 5

Summary of Creep Data Used to Produce Larson-Miller Plot

Material	Density (lb/in^3)	Stress-to-Density (10^4 in)	Test Temperature °F	Time for Indicated Creep (Hours) 0.5%	1.0%	Larson-Miller Parameter For Indicated Creep 0.5%	1.0%
Cb132M	0.347	2.13	2256	250	585	47.1	48.2
Cb132M	0.347	4.90	2056	340	680	44.1	44.9
Cb132M	0.347	5.76	2056	275	500	43.9	44.5
T-222	0.611	1.97	2200	360	620	46.7	47.3
T-222	0.611	3.14	2056	550	900	44.6	45.2
TZM	0.367	2.73	2000	1.5×10^4*	-	47.2	-
TZC	0.363	6.38	1856	1.5×10^4*	-	44.4	-
TZC	0.363	5.51	2000	7750*	-	46.5	-
TZC	0.363	5.23	2056	1.1×10^4*	-	47.9	-
TZC	0.363	4.95	2200	1100	2050	48.0	48.7
TZC	0.363	4.67	2200	2550	5310*	49.0	49.8
T-222	0.611	1.3	2200	4000	8×10^4*	49.5	50.4
(Ref. 9)	0.611	2.6	2000	2.5×10^4*	5×10^4*	47.6	50.9

* Predicted by extrapolation

linear extrapolations were made to provide the appropriate time.* Considering the high-strength refractory alloys on a stress-to-weight basis, the TZC material has creep resistance which is significantly superior to the other alloys. The data obtained in this program on T-222 indicate that it has creep resistance which is substantially inferior to the molybdenum-base alloys. For comparison purposes, data obtained by Titran and Hall (9) on T-222 material from a different heat, are also presented. At the lower value of applied stress, the creep behavior showed good agreement with the extrapolation of the data obtained in this program. At the stress-to-density ratio of 2.6×10^4 in, a considerable difference in the properties of the two heats is apparent. It should be noted, however, that the point plotted from Reference 9 was obtained by a rather lengthly extrapolation of a curve which involved only 0.1% creep in 5000 hours.

The slope of the creep data for the TZC material presented on the Larson-Miller plot is also considerably less than that experienced by other alloys. The presence of strain-induced precipitation in the TZC could contribute to this behavior.

5. Variation in Composition

Although many of the chemical analyses are still in progress, preliminary results indicate that no consistent variation in chemical composition had occurred in any of the materials as a result of creep test exposure. A summary of the interstitial composition both before and after testing for TZC, AS-30, Cb132M, W, and W-Re is presented in Table 6.

6. Thermocouple Drift Data

The design of the creep units incorporates a lamp calibrated at the start of the test so that any drift in the readings of the standard W-3%Re vs. W-25%Re thermocouple which is attached to the specimen can be measured. On this basis the actual test temperature can be maintained constant, independent of possible long-time degradation in thermocouple output. With the assumption that the emissivity of the standard lamp and the specimen does not change significantly with time (10) the available data allow an evaluation to be made of the drift in tungsten-rhenium thermocouples over extended time periods. Typical variations in thermocouple readings for times up to 5700 hours are shown in Figures 35 through 38. The true furnace temperature is maintained to within approximately

* In the case of the TZC alloys the extrapolations were made using the section of the creep curve which did not involve "negative" creep.

TABLE 6

Interstitial Composition of Refractory Metals

Before and After Creep Testing

Material	Test Time (Hours)	Test Temperature (°F)	Analysis ppm Before Test TRW	Analysis ppm Before Test Vendor	After Test	Element
TZC	1197	2000	800	1400	1500	Carbon
			41	5	23	Oxygen
			9	1	5	Hydrogen
			18	1	24	Nitrogen
AS-30	1193	2000	900	650	700	Carbon
			60	130 to 160	40	Oxygen
			15	3 to 6	9	Hydrogen
			10	15	17	Nitrogen
Cb132M	568	2000	1600	1500	1500	Carbon
			4	4	3	Oxygen
			4	4	2	Hydrogen
			4	4	3	Nitrogen
Tungsten (arc-cast)	32	3200	60	20	30	Carbon
			9	10	10	Oxygen
			4	1	5	Hydrogen
			16	11	10	Nitrogen
Tungsten (arc-cast)	3886	3200	60	20	40	Carbon
			9	10	37	Oxygen
			4	1	3	Hydrogen
			16	11	6	Nitrogen
W-25% Re	97	3200		50	60	Carbon
				<50	10	Oxygen
				1	5	Hydrogen
				30	10	Nitrogen

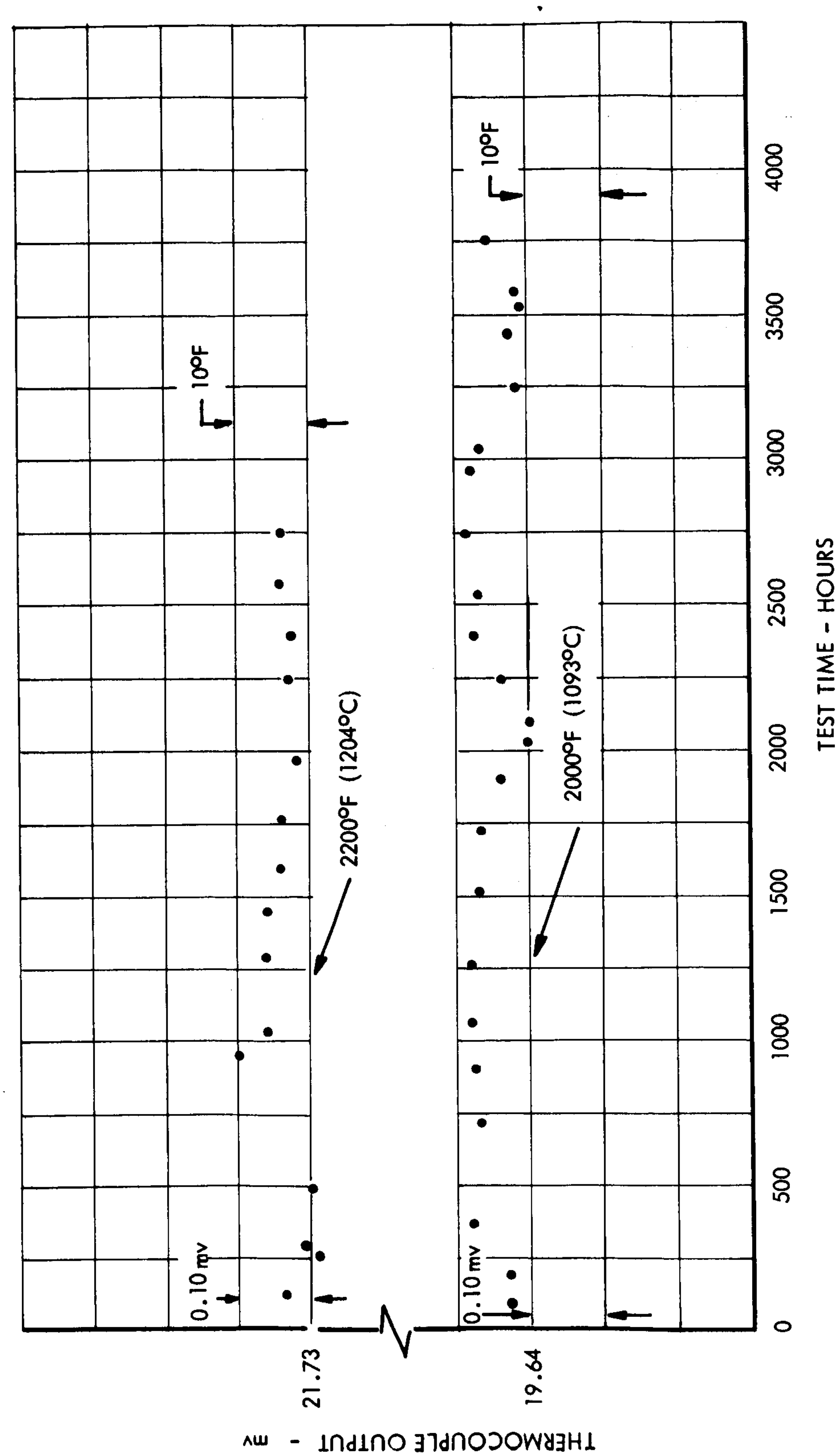


Figure 35. Variation in Thermocouple Output (W-3%Re Vs. W-25%Re) as a Function of Test Time in Vacuum Environment <1 x 10^{-8} Torr, Optical Standard, TZC Specimens.

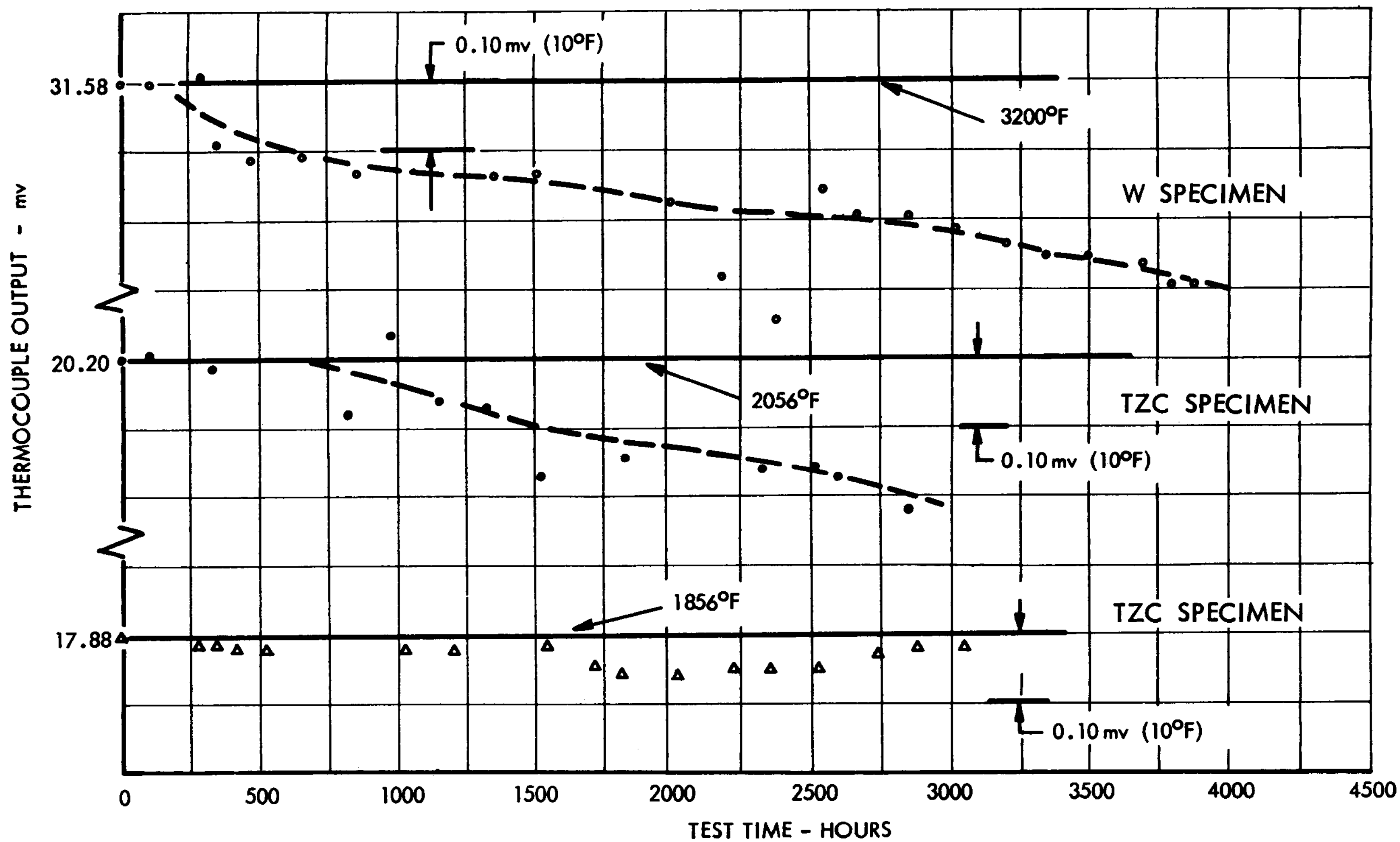


Figure 36. Variation in Thermocouple Output (W-3%Re Vs. W-25%Re) as a Function of Test Time in Vacuum Environment $< 1 \times 10^{-8}$ Torr, Optical Standard.

9966

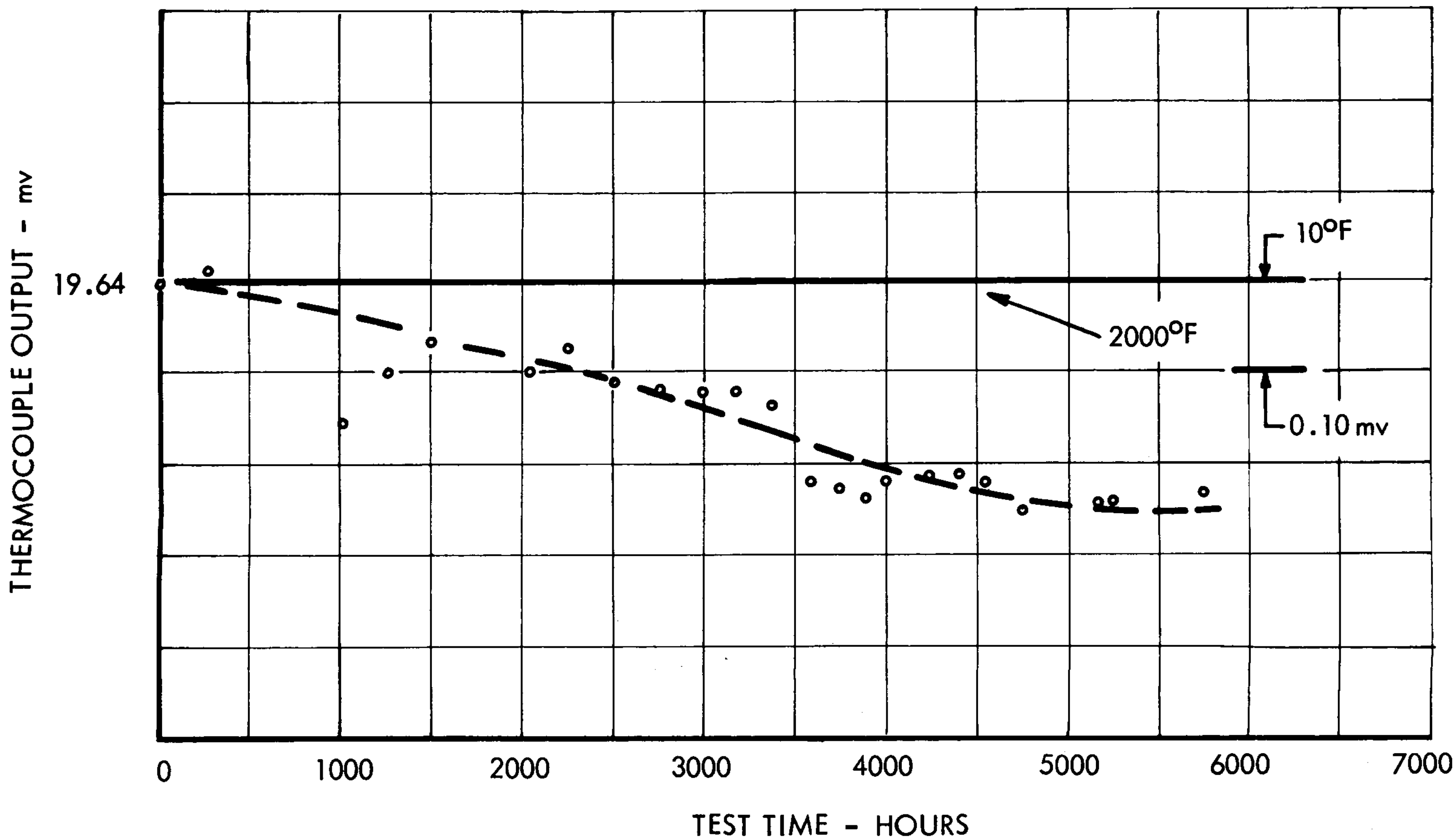


Figure 37. Variation in Thermocouple Output (W-3%Re Vs. W-25%Re) as a Function of Test Time in Vacuum Environment < 1 x 10^{-8} Torr, Optical Standard, TZM Specimen.

9796

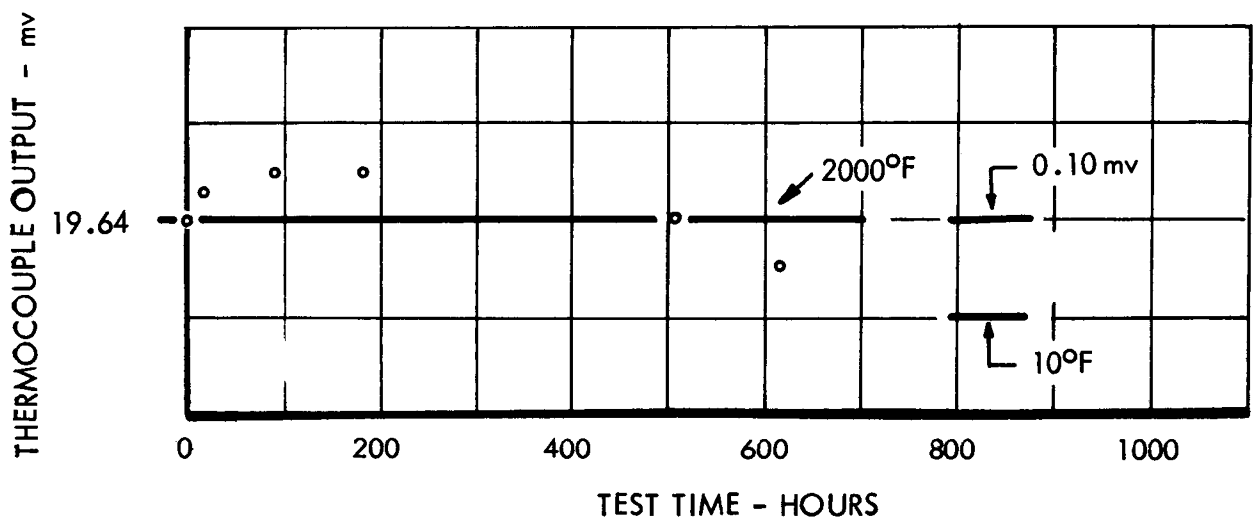


Figure 38. Variation in Thermocouple Output (W-3%Re Vs. W-25%Re) as a Function of Test Time in Vacuum Environment < 1 x 10^{-8} Torr, Optical Standard, AS-30 Specimen.

±2°F over extended time periods so deviations greater than this represent drift in thermocouple output. The results indicate that the most serious drift (see Figures 36 and 37) occurred as a decrease in the thermocouple output which can amount to values as high as 30°F at times greater than 3000 hours. The thermocouple drift, however, is not always consistent and there are tests where positive drift is actually observed (see Figures 35 and 38). Previous work had indicated that positive drifts are explainable on the basis of recovery or structure changes in the couples. Negative drifts, however, have been observed in short-time tests conducted at high temperatures in inert environments (11). At present no definite reason for the negative drift is apparent.

7. Future Work

Creep tests will be continued on TZC (Heat 90) and several heat treatments will be evaluated. Tests will be initiated on T-111 and a columbium-modified TZM alloy.

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APPENDIX I

Processing History of Test Materials

TABLE A-I

PROCESSING HISTORY OF TUNGSTEN SHEET

Vendor:

Universal Cyclops Steel Corporation
Bridgeville, Pennsylvania
Heat KC 1357

Processing History:

1) Extruded 4:1 ratio 3100°F (TRW)
2) Forged open die 2200°F
3) Rolled
    a) Initial 2300°F
    b) Intermediate 1800°F
    c) Final 1400°F
4) Stress relieved 1700°F

Hardness:

487 DPH
$48.0 R_C$ (converted from DPH)

TABLE A-II

PROCESSING HISTORY OF TUNGSTEN - 25% RHENIUM SHEET

Vendor:

Wah Chang Corporation
Albany Division
Heat 3.5 - 75002

Processing History:

1) 0.055" sheet stress relieved one hour 2375°F
2) rolled to 0.035"
3) 0.035" sheet stress relieved
   a) small sheet - 2375°F
   b) large sheet - 2550°F

Hardness:

452 DPH
45.1 R_c (converted from DPH)

TABLE A-III

PROCESSING HISTORY OF SYLVANIA "A" SHEET

Vendor:

Sylvania Electric Products, Inc.
Chemical and Metallurgical Division
Towanda, Pennsylvania
Sales Order 88-56713

Processing History:

1) Rolling slabs were made by isostatically pressing powder
2) Slabs rolled at 1500-1900°C to 0.032". Total reduction 90%
3) Intermediate annealing - none
4) Final stress relief - five minutes at 1500°C
5) Sheet trimmed with an abrasive saw and chemically cleaned

Hardness:

579 DPH
54.0 R_c (converted from DPH)

TABLE A-IV

PROCESSING HISTORY OF TZM FORGED DISC

Vendor:

Climax Molybdenum Company of America
Coldwater, Michigan
Heat 7502

Processing History:

1) Vacuum arc melted ingot 11-1/2" dia.
2) Machined to 10-3/4" dia.
3) Extruded to 6-1/4" dia.
4) Heat treated at 2700°F
5) Upset forged at 2200°F
6) Stress relieved at 2200°F

Hardness:

247 - 319 DPH
$99R_B$ - 32 R_c (converted from DPH)

TABLE A-V

PROCESSING HISTORY OF TZM FORGED DISC

Vendor:

Received from Air Research
Disc No. 3
Heat 1175

Processing History:

1) 11-3/4" dia. ingot, machine to 10-3/4" dia.
2) Extrude to 6-1/2" at 2250°F
3) Recrystallize at 2800°F for 4 hours
4) Forge to 4" dia. billet (3400°F to 2800°F)
5) Recrystallize at 2950°F for 2 hours
6) Forge to flat disc 3/4" thick, 2800°F starting temperature, 11 blows, finish temperature 2160°F.
7) Stress relieve at 2300°F for 1 hour.

Hardness:

247-319 DPH
$99R_B$-$32R_C$ (converted from DPH)

TABLE A-VI

PROCESSING HISTORY OF TZC PLATE

Vendor:

General Electric Company
Refractory Metals Plant
Cleveland, Ohio
Heat M-80

Processing History:

1) Vacuum arc melted ingot 5.88" dia.
2) Machine to 5" dia.
3) Extrude 2:30:1 ratio at 3092°F (1700°C) to 4-1/8" x 2.22" plate
4) Cross-rolled* at 2925°F (1585°C) in 4-1/8" direction to 0.740", hydrogen atmosphere, 12" dia. rolls, 4% reduction per pass
5) Grit blasted and cut to final length with abrasive saw.

Hardness:

296 DPH
29.4 R_c (converted from DPH)

*Reductions obtainable with small rolls (12" dia.) were considered insufficient to produce optimum structure and properties. As a result the processing for TZC was modified in Heat M-90, See Table A-VII.

TABLE A-VII

PROCESSING HISTORY OF TZC PLATE

Vendor:

General Electric Company
Refractory Metals Plant
Cleveland, Ohio
Heat M-91

Processing History:

1) Vacuum arc melt ingot 5.88" dia.
2) Machine to 5" dia.
3) Extrude 2.30:1 at 3092°F (1700°C) to 4-1/8" x 2.22" plate
4) Cross-roll on large mill (28" dia.) to produce relatively large degree of deformation per pass and a finishing temperature as low as 2372°F (1300°C)
5) Grit blast and cut to final length with abrasive saw

Hardness:

385 DPH
39 R_c (converted from DPH)

TABLE A-VIII

PROCESSING HISTORY OF AS-30 PLATE

Vendor:

General Electric Company
Refractory Metals Plant
Cleveland, Ohio
Heat No. C5

Processing History:

1) Vacuum arc melted ingot 5.4" dia.
2) Machined to 4.8" dia.
3) Jacket in molybdenum
4) Extrude 3.25:1 ratio at 2825°F to 4" x 1.625" sheet bar
5) Cross-rolled at 2100°F to 0.790"; argon atmosphere
6) Acid etched to remove molybdenum jacket
7) Abrasive sawed to final width and length

Hardness:

293 DPH
29.2 R_c (converted from DPH)

TABLE A-IX

PROCESSING HISTORY OF Cb132M PLATE

Vendor:

Universal Cyclops
Bridgeville, Pennsylvania
Heat No. KC 1454

Processing History:

1) Electron-beam melted stock with carbon added by Universal Cyclops, electrode diameter 2-1/2" mold size 3-7/8"
2) Vacuum arc melted, then canned in Mo-0.5Ti
3) Extruded at 3130°F to 1-1/2" diameter
4) Cross-rolled from 2400°F in three passes yielding reductions of 20, 10, and 10%. Plate reheated between each pass. Final thickness 3/4".
5) Jacket removed, shipped in as-rolled structure

Hardness:

336 DPH
34.2 R_c (converted from DPH)

TABLE A-X

PROCESSING HISTORY OF T-222 SHEET

Vendor:

Westinghouse Electric Corp.
Astronuclear Lab.
Heat No. AL-TA-43

Processing History:

1) Ingot 4-1/2" dia. x 4-1/2" long
2) Side forged to 1-1/2" thick (final forging 1-1/2" x 4-1/2" x 5-1/2"
3) Rolled in 5-1/2" direction to 0.700" thick
4) Cut to 0.700" x 4" x 9" size, final rolling direction parallel to 9" dimension
5) Rolled to 0.030" thickness

Hardness:

413 DPH
42.0 R_c (converted from DPH)

TABLE A-XI

PROCESSING HISTORY OF T-111 SHEET

Vendor:

Wah Chang Corporation
Albany Division
Heat No. 70616-T-111

Processing History:

1) Electron beam melt
2) Arc cast 5-1/2" ingot
3) Forge to 1-1/2" thick sheet bar - 2200°F
4) Vacuum anneal 2400°F
5) Warm roll 800°F to 200 mil thick
6) Vacuum anneal 2400°F
7) Cold roll to final thickness
8) Vacuum anneal 2400°F

Hardness:

210 DPH
94 R_B (converted from DPH)

APPENDIX II

ORIENTATION OF TEST SPECIMENS AND SPECIMEN CONFIGURATION

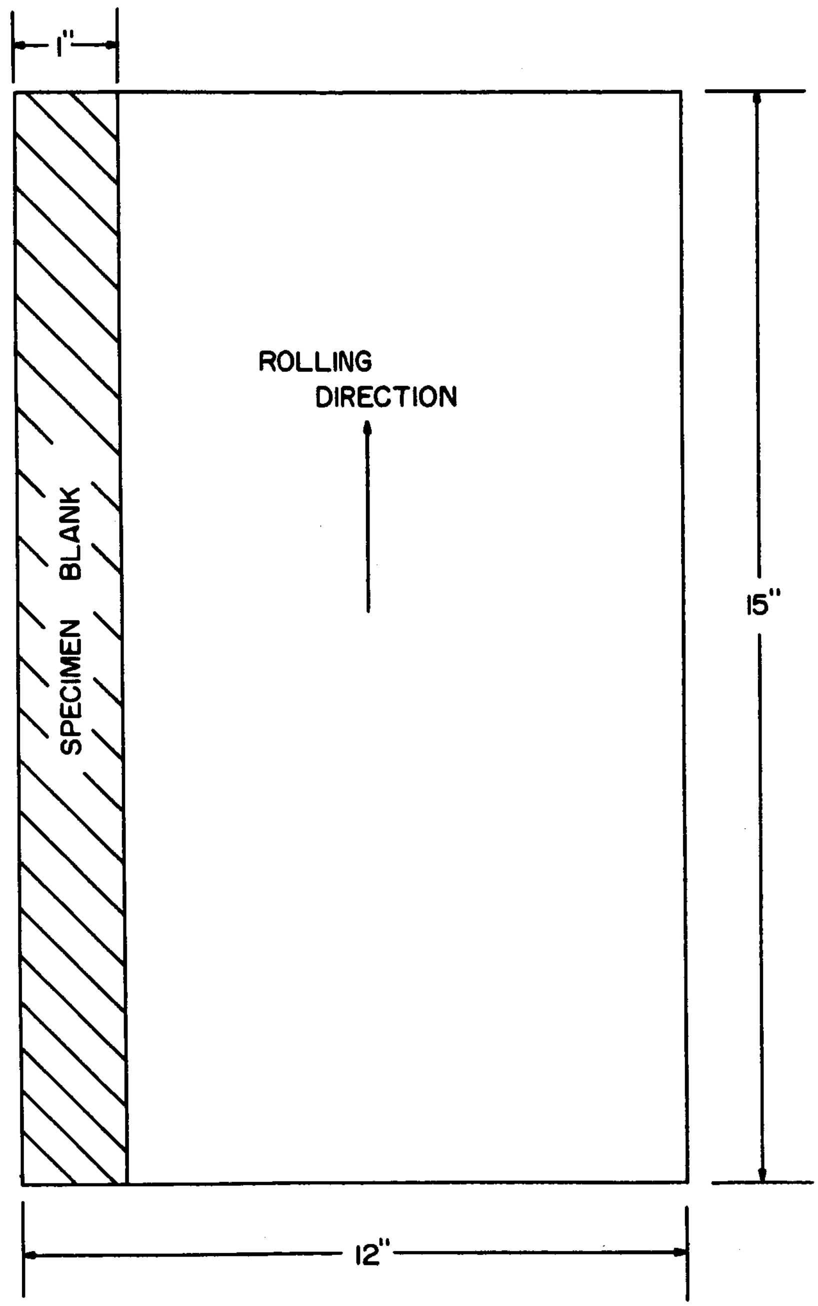


FIG. A-1 LOCATION OF SPECIMEN ON SHEET STOCK.

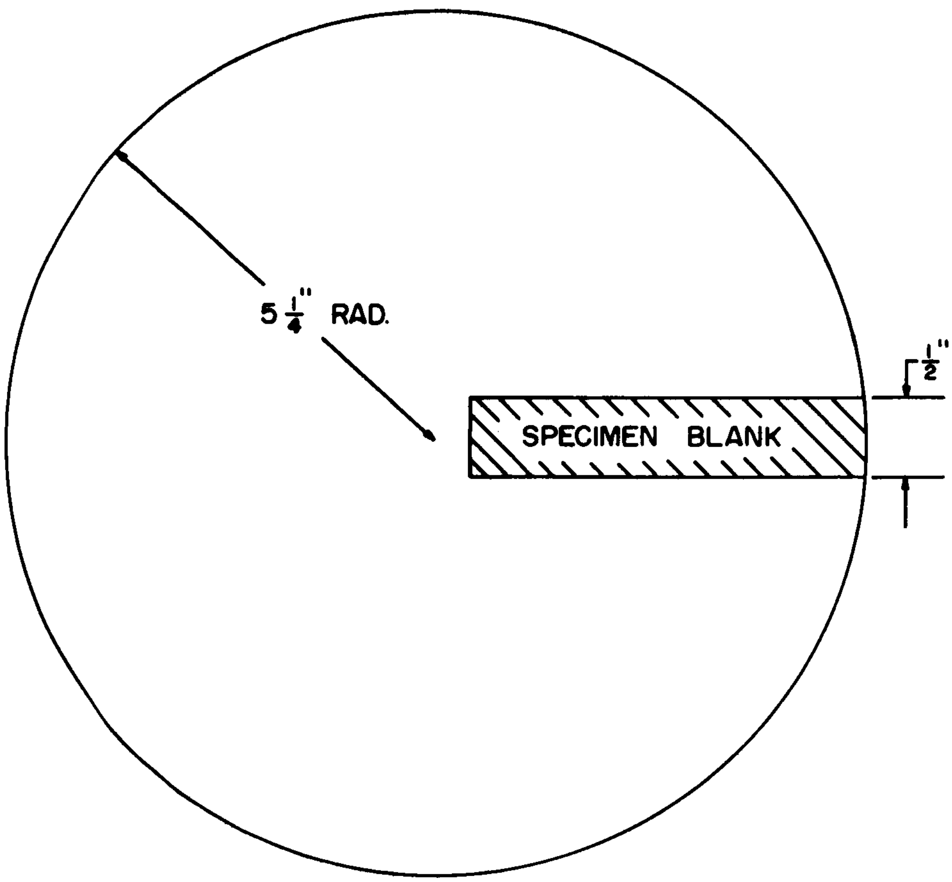


FIG. A-2 LOCATION OF SPECIMEN ON FORGED DISC.

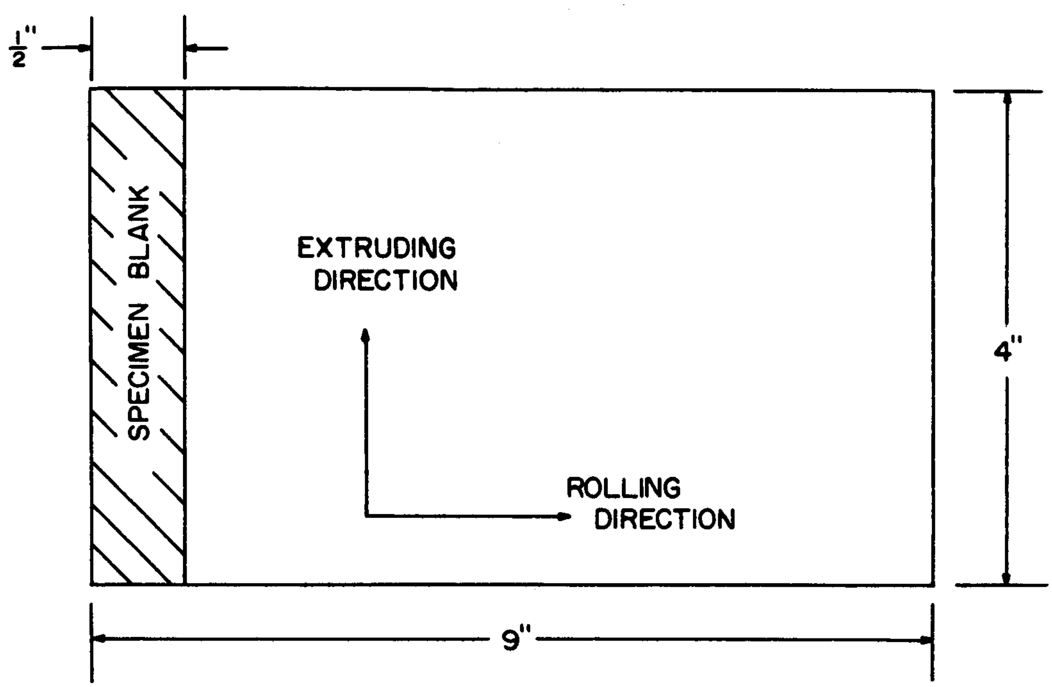
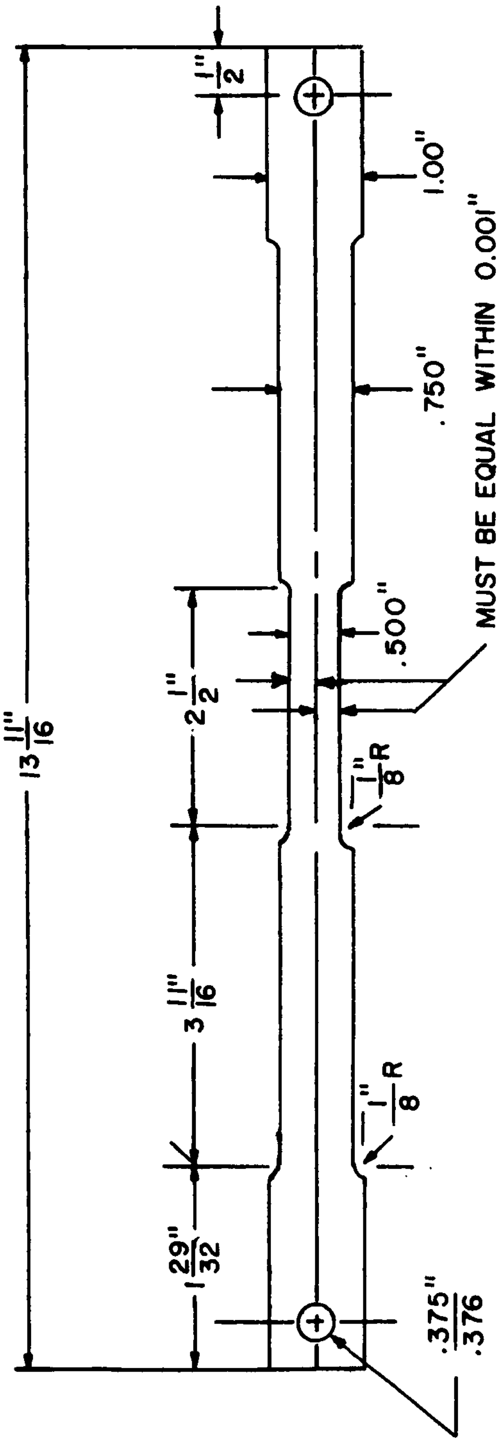
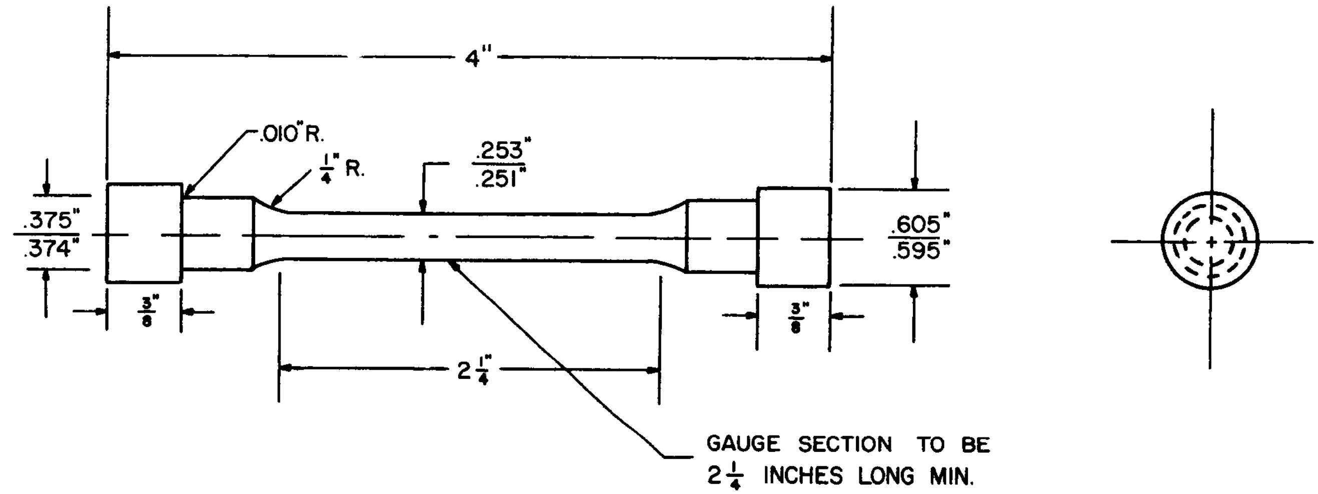


FIG. A-3 LOCATION OF SPECIMEN ON EXTRUDED AND ROLLED PLATE.



A-4 CREEP SPECIMEN USED FOR SHEET STOCK

7627



NOTE: ANY TAPER IN GAUGE SECTION MUST BE TOWARDS CENTER

ALL TOLERANCES ± .010" UNLESS OTHERWISE NOTED

FIG. A-5 CREEP SPECIMEN USED FOR DISC AND PLATE STOCK.

APPENDIX III

CREEP TEST DATA

TABLE I

CREEP TEST DATA, TUNGSTEN SHEET, 1000 PSI (6.89×10^6 N/m^2)

TESTED AT 3200°F (1760°C)

RECRYSTALLIZED AT 3200°F (1760°C), 2 HOURS

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
1 minute	.00005	.002	4×10^{-8}
2	.00015	.007	
3	.00015	.007	
4	.00010	.005	
5	.00015	.007	
6	.00020	.010	
7	.00020	.010	
8	.00020	.010	
9	.00020	.010	
10	.00015	.007	
15	.00020	.010	
20	.00010	.005	
25	.00020	.010	
30	.00020	.010	
60	.00020	.010	
90	.00030	.015	
16.6 hours	.00180	.090	2.2×10^{-8}
88.4	.00480	.240	1.0×10^{-8}
112.4	.00615	.308	1.1×10^{-8}
136.3	.00750	.375	9.2×10^{-9}
160.3	.00880	.440	7.8×10^{-9}
184.4	.00960	.480	6.9×10^{-9}
256.3	.01115	.558	5.6×10^{-8}
280.7	.01190	.595	1.6×10^{-8}
340.5	.01215	.608	3.9×10^{-9}
328.4	.01265	.632	6.8×10^{-9}
352.7	.01330	.665	6.5×10^{-9}
424.5	.01575	.788	7.2×10^{-9}
448.9	.01725	.862	6.1×10^{-9}
472.3	.01705	.852	6.3×10^{-9}
496.4	.01725	.862	9.0×10^{-9}
520.4	.01740	.870	4.6×10^{-8}
592.4	.01810	.905	5.0×10^{-8}
619.1	.01930	.965	3.6×10^{-8}

TABLE I (Continued)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
640.3 hours	.01960	.980	4.9×10^{-8}
664.3	.02010	1.005	4.7×10^{-8}
688.2	.02040	1.020	4.0×10^{-8}
760.4	.02155	1.077	4.6×10^{-9}
784.6	.02190	1.095	1.5×10^{-8}
808.7	.02305	1.152	7.2×10^{-9}
832.3	.02375	1.188	2.4×10^{-9}
856.3	.02455	1.228	2.4×10^{-9}
928.5	.02465	1.232	3.0×10^{-9}
952.5	.02570	1.285	2.3×10^{-9}
977.5	.02660	1.330	8.2×10^{-9}
1000.3	.02715	1.358	2.4×10^{-9}
1026.3	.02775	1.388	--
1096.6	.02850	1.425	8.3×10^{-9}
1121.1	.02875	1.438	8.0×10^{-9}
1144.3	.02930	1.465	--
1168.4	.03040	1.520	9.4×10^{-9}
1264.3	.03120	1.560	9.2×10^{-9}
1288.4	.03145	1.572	2.8×10^{-9}
1312.4	.03210	1.655	6.7×10^{-9}
1336.9	.03265	1.632	2.4×10^{-9}
1360.5	.03300	1.650	--
1431.6	.03345	1.672	4.6×10^{-10}
1455.4	.03430	1.715	2.4×10^{-9}
1479.4	.03445	1.722	3.2×10^{-9}
1503.2	.03455	1.728	6.8×10^{-9}
1527.5	.03460	1.730	6.6×10^{-9}
1599.8	.03525	1.762	5.3×10^{-9}
1623.3	.03550	1.775	3.0×10^{-9}
1652.7	.03630	1.815	--
1671.4	.03665	1.832	1.8×10^{-9}
1691.6	.03690	1.845	2.0×10^{-9}
1767.3	.03745	1.872	1.8×10^{-9}
1791.8	.03810	1.905	1.7×10^{-9}
1815.4	.03825	1.912	1.7×10^{-9}
1839.3	.03850	1.925	6.0×10^{-9}
1863.3	.03865	1.932	3.2×10^{-10}
1935.6	.03910	1.955	6.2×10^{-9}
1983.5	.04010	2.005	2.5×10^{-9}
2031.7	.04040	2.020	7.3×10^{-9}
2103.2	.04100	2.050	2.2×10^{-9}

TABLE I (Continued)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
2157.7	.04135	2.068	7.4×10^{-9}
2199.5	.04180	2.090	--
2248.8	.04205	2.102	--
2295.3	.04260	2.130	2.3×10^{-9}
2320.2	.04275	2.138	2.8×10^{-9}
2367.3	.04325	2.162	2.0×10^{-9}
2439.2	.04370	2.185	2.1×10^{-9}
2487.4	.04420	2.210	2.0×10^{-9}
2535.3	.04465	2.232	6.6×10^{-9}
2607.3	.04555	2.278	1.4×10^{-9}
2660.1	.04620	2.310	7.0×10^{-9}
2703.3	.04570	2.285	5.6×10^{-9}
2775.2	.04710	2.355	1.7×10^{-9}
2847.5	.04770	2.385	1.6×10^{-9}
2943.6	.04850	2.425	2.0×10^{-9}
3015.4	.04940	2.470	5.0×10^{-9}
3135.6	.05090	2.545	5.9×10^{-9}
3184.0	.05110	2.555	5.9×10^{-9}
3279.3	.05145	2.572	2.6×10^{-9}
3351.6	.05215	2.608	6.2×10^{-9}
3447.8	.05320	2.660	3.4×10^{-9}
3519.4	.05355	2.678	1.5×10^{-9}
3618.5	.05405	2.702	2.0×10^{-9}
3692.2	.05420	2.710	1.1×10^{-8}
3793.5	.05475	2.738	2.4×10^{-8}
3856.9	.05510	2.755	4.9×10^{-8}
3886.4	.05520	2.760	1.1×10^{-7}

Test terminated because of high pressure due to leak.

TABLE II

CREEP TEST DATA, SYLVANIA "A" ALLOY SHEET, RECRYSTALLIZED 1-2 HOURS AT 3200°F (1760°C), 2 HOURS TESTED AT 3200°F (1760°C), 5000 PSI (3.45×10^7 N/m^2),

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
2 minutes	.00050	.025	1.7×10^{-7}
3	.00070	.035	
4	.00095	.048	
5	.00060	.030	
6	.00075	.038	
7	.00080	.040	
8	.00080	.040	
9	.00075	.038	
10	.00085	.042	
15	.00085	.042	
20	.00095	.048	
25	.00085	.042	
30	.00085	.042	
18.4 hours	.01170	.585	1.6×10^{-7}
21.4	.01330	.665	4.6×10^{-7}
26.5	.01595	.798	--
41.5	.02380	1.190	--
42.0	.02395	1.198	1.1×10^{-7}
50.4	.02895	1.448	1.0×10^{-7}
91.6	.05030	2.515	--
114.2	.06605	3.302	1.0×10^{-7}
138.3	.08135	4.068	8.8×10^{-8}
162.3	.10495	5.247	8.4×10^{-8}
170.3	.10500	5.250	--

Test terminated after reaching 5% creep.

TABLE III

CREEP TEST DATA, SYLVANIA "A" ALLOY SHEET, RECRYSTALLIZED AT 3200°F (1760°C), 2 HOURS TESTED AT 3200°F (1760°C), 3000 PSI (2.07×10^7 N/m^2),

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
2 minutes	.00000	.000	6.4×10^{-7}
4	-.00040	.020	
6	-.00050	.025	
8	-.00060	.030	
10	-.00060	.030	
30	-.00070	.035	
60	-.00070	.035	
1.2 hours	.00130	.065	3.2×10^{-7}
2.3	.00140	.070	--
68.7	.00650	.325	2.0×10^{-8}
91.3	.00730	.365	1.7×10^{-8}
115.0	.00855	.478	1.5×10^{-8}
139.3	.01030	.515	1.6×10^{-8}
163.2	.01275	.638	1.4×10^{-8}
235.2	.01865	.932	1.2×10^{-8}
260.4	.02065	1.032	1.1×10^{-8}
283.5	.02280	1.140	1.0×10^{-8}
307.2	.02450	1.225	9.6×10^{-9}
331.0	.02715	1.358	8.8×10^{-9}
402.9	.03365	1.682	8.4×10^{-9}
426.9	.03540	1.770	7.7×10^{-9}
451.0	.03865	1.932	7.3×10^{-9}
475.1	.04075	2.038	7.9×10^{-9}
499.1	.04315	2.158	7.6×10^{-9}
571.1	.05270	2.635	6.1×10^{-9}
595.0	.05540	2.770	6.0×10^{-9}
619.0	.05960	2.980	5.9×10^{-9}
642.9	.06360	3.180	6.0×10^{-9}
667.1	.06740	3.370	5.8×10^{-9}
763.0	.08400	4.200	5.3×10^{-9}
787.0	.08930	4.465	5.2×10^{-9}
811.1	.09470	4.735	5.7×10^{-9}
835.1	.10000	5.000	5.0×10^{-9}
907.1	.11725	5.862	2.0×10^{-9}

Test terminated after reaching 5% creep.

TABLE IV

CREEP TEST DATA, TZM FORGED DISC HEAT # 7502, ANNEALED AT 2850°F (1566°C), FOR 1 HOUR, TESTED AT 2000°F (1093°C) 10,000 PSI (6.89×10^7 N/m^2)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1 minute(s)	.00030	.015	
2	.00045	.022	
3	.00040	.020	
4	.00030	.015	
5	.00025	.012	
6	.00015	.008	
7	.00015	.008	
8	.00010	.005	
9	.00020	.010	
10	.00030	.015	
11	.00030	.015	
12	.00025	.012	
13	.00030	.015	
14	.00030	.015	
15	.00035	.018	
20	.00045	.022	
25	.00050	.025	
30	.00055	.028	
35	.00050	.025	
40	.00050	.025	
45	.00050	.025	
60	.00050	.025	
16.6 hours	.00040	.020	6.2×10^{-9}
40.7	.00055	.028	3.1×10^{-9}
114.5	.00095	.048	5.1×10^{-9}
136.5	.00105	.052	3.0×10^{-9}
160.4	.00120	.060	3.4×10^{-9}
184.4	.00130	.065	2.4×10^{-9}
208.3	.00140	.070	2.3×10^{-9}
287.5	.00180	.090	2.2×10^{-9}
304.7	.00235	.118	1.8×10^{-9}
328.7	.00505	.252	1.6×10^{-9}
336.5	.00485	.242	--
352.6	.00515	.258	1.6×10^{-9}
376.4	.00525	.262	2.2×10^{-9}
448.3	.00525	.262	1.4×10^{-9}
472.7	.00525	.262	1.0×10^{-9}
496.6	.00530	.265	1.0×10^{-9}

TABLE IV (Continued)

CREEP TEST DATA, TZM FORGED DISC HEAT #7502, ANNEALED AT 2850°F (1566°C), FOR 1 HOUR, TESTED AT 2000°F (1093°C) 10,000 PSI (6.89×10^7 N/m^2)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
520.8 hours	.00535	.268	1.6×10^{-9}
544.6	.00565	.282	1.2×10^{-9}
616.6	.00560	.280	6.2×10^{-10}
640.5	.00555	.278	7.2×10^{-10}
664.6	.00560	.280	7.2×10^{-10}
688.7	.00560	.280	7.3×10^{-10}
712.8	.00565	.282	1.3×10^{-9}
784.6	.00560	.280	5.6×10^{-10}
808.7	.00555	.278	5.5×10^{-10}
832.6	.00565	.282	5.8×10^{-10}
856.6	.00575	.288	5.8×10^{-10}
880.6	.00580	.290	6.6×10^{-10}
952.6	.00480	.240	4.3×10^{-10}
977.0	.00485	.242	1.4×10^{-9}
1000.7	.00485	.242	4.2×10^{-10}
1025.0	.00505	.252	7.2×10^{-10}
1049.3	.00440	.220	4.6×10^{-10}
1120.8	.00465	.232	3.2×10^{-10}
1145.2	.00485	.242	4.3×10^{-10}
1168.5	.00505	.252	5.0×10^{-10}
1192.7	.00515	.258	8.0×10^{-10}
1216.6	.00515	.258	3.0×10^{-10}
1288.6	.00510	.255	1.6×10^{-10}
1315.5	.00525	.262	2.2×10^{-10}
1336.5	.00525	.262	1.5×10^{-10}
1360.7	.00520	.260	1.6×10^{-10}
1384.5	.00525	.262	2.1×10^{-10}
1456.6	.00540	.270	4.4×10^{-10}
1480.9	.00520	.260	1.6×10^{-9}
1505.0	.00505	.252	9.7×10^{-11}
1528.5	.00510	.255	1.3×10^{-9}
1552.8	.00520	.260	1.3×10^{-9}
1649.0	.00530	.265	9.3×10^{-10}
1696.6	.00535	.268	--
1722.7	.00530	.265	--
1792.8	.00530	.265	3.2×10^{-12}
1840.7	.00530	.265	8.8×10^{-11}
1864.8	.00530	.265	1.2×10^{-9}

TABLE IV (Continued)

CREEP TEST DATA, TZM FORGED DISC HEAT #7502, ANNEALED AT 2850°F (1566°C), FOR 1 HOUR, TESTED AT 2000°F (1093°C) 10,000 PSI (6.89 x 10^7 N/m^2)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1960.8 hours	.00540	.270	9.6 x 10^{-10}
1984.8	.00545	.272	3.6 x 10^{-10}
2008.6	.00545	.272	1.5 x 10^{-9}
2056.9	.00550	.275	--
2115.2	.00555	.278	3.2 x 10^{-10}
2163.0	.00550	.275	8.0 x 10^{-10}
2211.2	.00545	.272	1.4 x 10^{-9}
2283.4	.00560	.280	1.1 x 10^{-9}
2336.3	.00560	.280	--
2380.1	.00550	.275	1.4 x 10^{-11}
2450.9	.00555	.278	1.4 x 10^{-11}
2523.0	.00570	.285	1.0 x 10^{-9}
2619.2	.00570	.285	8.6 x 10^{-10}
2691.0	.00610	.305	--
2786.8	.00635	.318	2.5 x 10^{-10}
2859.8	.00640	.320	8.8 x 10^{-11}
2932.3	.00640	.320	1.4 x 10^{-10}
2978.9	.00640	.320	2.2 x 10^{-10}
3027.0	.00580	.290	1.2 x 10^{-10}
3122.9	.00630	.315	2.6 x 10^{-10}
3195.2	.00605	.302	2.8 x 10^{-10}
3291.1	.00640	.320	3.5 x 10^{-11}
3363.0	.00650	.325	1.2 x 10^{-9}
3458.8	.00645	.322	2.4 x 10^{-10}
3531.2	.00655	.328	9.2 x 10^{-10}
3627.1	.00640	.320	2.4 x 10^{-11}
3699.0	.00655	.328	4.2 x 10^{-10}
3819.2	.00630	.315	5.6 x 10^{-10}
3891.0	.00620	.310	6.6 x 10^{-10}
3963.1	.00640	.320	4.3 x 10^{-11}
4035.2	.00640	.320	1.0 x 10^{-11}
4131.4	.00670	.335	8.4 x 10^{-10}
4203.0	.00685	.342	1.9 x 10^{-11}
4301.7	.00690	.345	3.0 x 10^{-10}
4374.3	.00680	.340	1.7 x 10^{-10}
4477.1	.00700	.350	2.0 x 10^{-10}
4541.4	.00700	.350	2.3 x 10^{-9}
4636.7	.00700	.350	2.4 x 10^{-9}
4707.2	.00700	.350	2.6 x 10^{-9}

TABLE IV (Continued)

CREEP TEST DATA, TZM FORGED DISC HEAT #7502, ANNEALED AT 2850°F (1566°C), FOR 1 HOUR, TESTED AT 2000°F (1039°C), 10,000 PSI (6.89×10^7 N/m^2)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
4803.3 hours	.00705	.352	1.2×10^{-9}
4875.2	.00705	.352	3.1×10^{-9}
4970.9	.00710	.355	1.7×10^{-9}
5043.3	.00715	.358	3.0×10^{-9}
5139.1	.00690	.345	2.6×10^{-9}
5210.0	.00730	.365	2.6×10^{-9}
5331.1	.00725	.362	3.4×10^{-9}
5379.1	.00720	.360	2.1×10^{-9}
5475.2	.00720	.360	2.0×10^{-9}
5547.3	.00720	.360	2.1×10^{-9}
5643.5	.00730	.365	1.9×10^{-9}
5715.9	.00730	.365	2.3×10^{-9}

Test in Progress

TABLE V

CREEP TEST DATA FOR TZM MATERIAL RECEIVED FROM NASA DISC #3, TESTED AT 1856°F (1013°C), 23,400 PSI (1.6×10^8 N/m^2)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
1 minutes	-.00010	-.005	3.2×10^{-7}
2	-.00015	-.008	
3	-.00010	-.005	
4	-.00005	-.002	
5	-.00010	-.005	
6	-.00010	-.005	
7	-.00010	-.005	
8	-.00005	-.002	
9	-.00010	-.005	
10	-.00005	-.002	
15	-.00020	-.010	
30	-.00020	-.010	
60	-.00015	-.008	
66.9 hours	-.00010	-.005	3.7×10^{-8}
88.5	-.00005	-.002	2.2×10^{-8}
117.1	-.00005	-.002	2.3×10^{-8}
136.4	.00000	.000	1.6×10^{-8}
160.4	.00005	.002	1.6×10^{-8}
232.2	.00020	.010	9.8×10^{-9}
256.7	.00015	.008	8.8×10^{-9}
280.6	.00020	.010	5.6×10^{-9}
304.5	.00020	.010	6.7×10^{-9}
329.8	.00030	.015	6.1×10^{-9}
400.4	.00025	.012	4.2×10^{-9}
424.4	.00030	.015	3.7×10^{-9}
448.7	.00035	.018	3.4×10^{-9}
472.4	.00040	.020	2.6×10^{-9}
496.5	.00040	.020	1.5×10^{-9}
592.6	.00040	.020	1.8×10^{-9}
616.5	.00045	.022	1.4×10^{-9}
640.7	.00035	.018	1.6×10^{-9}
664.3	.00030	.015	1.6×10^{-9}
736.3	.00035	.018	1.1×10^{-9}
760.9	.00030	.015	1.0×10^{-9}
784.4	.00030	.015	1.3×10^{-9}
808.7	.00035	.018	1.4×10^{-9}
832.1	.00050	.025	1.0×10^{-9}
904.8	.00045	.022	1.2×10^{-9}
928.5	.00050	.025	1.0×10^{-9}
952.6	.00060	.030	8.2×10^{-10}
976.5	.00050	.025	5.2×10^{-10}

TABLE V (Continued)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
1075.2 hours	.00050	.025	--
1149.3	.00050	.025	8.4×10^{-10}
1250.5	.00045	.022	6.8×10^{-10}
1313.6	.00065	.032	3.6×10^{-10}
1410.1	.00055	.028	5.7×10^{-10}
1504.7	.00055	.028	1.2×10^{-9}
1576.4	.00060	.030	5.5×10^{-10}
1648.7	.00080	.040	1.1×10^{-9}
1744.3	.00080	.040	1.1×10^{-9}
1816.5	.00085	.042	1.1×10^{-9}
1912.5	.00080	.040	1.1×10^{-9}
1984.4	.00080	.040	1.0×10^{-9}
2104.5	.00075	.038	1.1×10^{-9}
2152.5	.00070	.035	5.0×10^{-10}
2248.5	.00075	.038	4.9×10^{-10}
2320.7	.00070	.035	1.0×10^{-9}
2416.9	.00065	.032	1.0×10^{-9}
2489.3	.00065	.032	5.7×10^{-10}

Test in progress.

TABLE VI

CREEP TEST DATA, TZM MATERIAL RECEIVED FROM NASA DISC #3, TESTED AT 1600°F (871°C)

55,000 PSI ($3.79 \times 10^8 N/m^2$)

Time		Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
1	minutes	.00000	.000	6.3×10^{-9}
2		.00000	.000	
3		.00005	-.002	
4		.00005	.002	
5		.00005	.002	
6		.00000	.000	
7		.00000	.000	
8		.00010	.005	
9		.00015	.008	
10		.00010	.005	
15		.00030	.015	
30		.00015	.008	
60		.00020	.010	
21.2	hours	.00020	.010	3.4×10^{-9}
45.5		.00025	.012	2.6×10^{-9}
69.2		.00015	.008	2.2×10^{-9}
141.2		.00020	.010	1.6×10^{-9}
165.1		.00035	.012	1.6×10^{-9}
189.2		.00030	.015	1.4×10^{-9}
213.2		.00030	.015	1.3×10^{-9}
237.2		.00035	.018	1.4×10^{-9}
333.2		.00035	.018	1.2×10^{-9}
357.7		.00025	.012	1.1×10^{-9}
381.1		.00030	.015	1.1×10^{-9}
405.2		.00025	.012	1.1×10^{-9}
477.3		.00030	.015	1.1×10^{-9}
501.1		.00025	.012	9.5×10^{-10}
525.1		.00030	.015	1.1×10^{-9}
549.4		.00035	.018	1.1×10^{-9}
573.4		.00040	.020	--
645.7		.00035	.018	1.1×10^{-9}
669.4		.00030	.015	1.1×10^{-9}
693.2		.00030	.015	1.1×10^{-9}
741.2		.00030	.015	1.1×10^{-9}

Test in Progress.

TABLE VII

CREEP TEST DATA, STRESS-RELIEVED TZM FORGED DISC, HEAT NO. 7502, TESTED AT 2000°F (1093°C), 10,000 PSI ($6.89 \times 10^7 N/m^2$)

Time		Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
1	minutes	-.00030	-.015	1.6×10^{-7}
2		-.00015	-.008	
3		-.00015	-.008	
4		-.00015	-.008	
5		-.00005	-.002	
6		.00010	.005	
7		.00005	.002	
8		.00000	.000	
9		.00010	.005	
10		.00005	.002	
15		.00005	.002	
20		.00010	.005	
25		.00005	.002	
30		.00000	.000	
45		.00010	.005	
60		.00015	.008	
75		.00005	.002	
90		.00010	.005	
20.0	hours	-.00005	-.002	6.7×10^{-8}
74.7		.00030	.015	1.0×10^{-8}
125.7		.00100	.050	1.4×10^{-8}
136.5		.00800	.040	1.0×10^{-8}
160.3		.00085	.042	5.7×10^{-9}
184.4		.00085	.042	4.4×10^{-9}
208.5		.00090	.045	4.0×10^{-9}
232.2		.00090	.045	3.4×10^{-9}
304.4		.00100	.050	2.2×10^{-9}
328.3		.00100	.050	2.0×10^{-9}
352.2		.00105	.052	1.9×10^{-9}
376.6		.00105	.052	1.3×10^{-9}
400.8		.00110	.055	2.1×10^{-9}
457.5		.00130	.065	1.3×10^{-9}
472.6		.00135	.068	1.2×10^{-9}
497.0		.00140	.070	1.2×10^{-9}

TABLE VII (Continued)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
520.2 hours	.00145	.072	1.2×10^{-9}
544.1	.00145	.072	1.2×10^{-9}
568.2	.00150	.075	1.2×10^{-9}
640.2	.00155	.078	1.5×10^{-9}
664.3	.00170	.085	9.2×10^{-10}
688.6	.00175	.088	6.0×10^{-10}
712.3	.00175	.088	7.4×10^{-10}
736.3	.00170	.085	7.6×10^{-10}
810.2	.00175	.088	1.3×10^{-9}
832.2	.00185	.092	9.0×10^{-10}
856.1	.00180	.090	9.2×10^{-10}
880.1	.00200	.100	7.5×10^{-10}
904.0	.00205	.102	7.7×10^{-10}
982.8	.00210	.105	8.1×10^{-10}
1000.2	.00210	.105	7.6×10^{-10}
1024.2	.00210	.105	8.2×10^{-10}
1048.3	.00220	.110	8.0×10^{-10}
1072.1	.00220	.110	1.3×10^{-9}
1144.0	.00230	.115	6.9×10^{-10}
1168.3	.00235	.118	6.9×10^{-10}
1192.2	.00240	.120	6.6×10^{-10}
1216.4	.00250	.125	6.4×10^{-10}
1240.2	.00250	.125	5.8×10^{-10}
1336.2	.00250	.125	5.9×10^{-9}
1360.3	.00250	.125	5.8×10^{-10}
1384.3	.00250	.125	5.2×10^{-10}
1408.5	.00250	.125	4.4×10^{-10}
1480.3	.00260	.130	4.6×10^{-10}
1552.2	.00270	.135	4.6×10^{-10}
1648.3	.00320	.160	4.0×10^{-10}
1696.4	.00320	.160	3.8×10^{-10}
1720.6	.00320	.160	4.4×10^{-10}
1816.4	.00320	.160	5.7×10^{-10}
1864.2	.00315	.158	3.8×10^{-10}
1912.3	.00325	.162	4.0×10^{-10}
1984.3	.00330	.165	2.6×10^{-10}
2032.2	.00335	.168	3.6×10^{-10}
2080.1	.00340	.170	3.1×10^{-10}
2152.3	.00340	.170	2.8×10^{-10}

TABLE VII (Continued)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
2200.6 hours	.00335	.168	2.3×10^{-10}
2248.4	.00340	.170	1.6×10^{-10}
2320.4	.00350	.175	2.7×10^{-10}
2369.4	.00345	.172	2.0×10^{-10}
2418.3	.00355	.178	9.2×10^{-11}
2488.4	.00345	.172	4.0×10^{-10}
2536.1	.00350	.175	1.7×10^{-10}
2560.3	.00345	.172	2.6×10^{-10}
2656.3	.00355	.178	2.6×10^{-10}
2704.3	.00350	.175	--
2752.4	.00350	.175	--
2823.5	.00355	.178	2.5×10^{-10}
2871.3	.00365	.182	1.1×10^{-11}
2919.5	.00375	.188	1.7×10^{-10}
2991.7	.00380	.190	7.2×10^{-11}
3044.5	.00380	.190	--
3088.4	.00380	.190	1.8×10^{-11}
3159.2	.00385	.192	1.6×10^{-11}
3231.2	.00390	.195	1.4×10^{-10}
3327.5	.00385	.192	1.2×10^{-10}
3399.4	.00395	.198	2.0×10^{-11}
3495.1	.00400	.200	8.2×10^{-12}
3568.1	.00400	.200	9.5×10^{-11}
3640.6	.00410	.205	3.4×10^{-11}
3687.2	.00410	.205	1.9×10^{-11}
3735.3	.00415	.208	1.0×10^{-11}
3831.1	.00420	.210	1.2×10^{-11}
3903.5	.00425	.212	2.1×10^{-11}
3999.2	.00440	.220	1.0×10^{-11}
4071.3	.00450	.225	2.1×10^{-11}
4167.1	.00450	.225	1.8×10^{-10}
4239.4	.00465	.232	1.8×10^{-11}
4335.4	.00460	.230	1.8×10^{-10}
4407.3	.00465	.232	1.0×10^{-11}
4527.5	.00465	.232	1.2×10^{-11}
4575.9	.00475	.238	1.0×10^{-11}

TABLE VII (Continued)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
4671.2 hours	.00470	.235	7.5×10^{-11}
4743.5	.00475	.238	1.0×10^{-11}
4839.7	.00470	.235	1.8×10^{-11}
4911.3	.00470	.235	1.0×10^{-11}
5010.3	.00475	.238	8.5×10^{-11}
5084.1	.00475	.238	1.8×10^{-10}
5185.4	.00485	.242	3.4×10^{-10}
5249.1	.00490	.245	9.3×10^{-10}
5344.9	.00480	.240	4.2×10^{-10}
5415.6	.00500	.250	4.2×10^{-10}
5511.5	.00505	.252	1.1×10^{-9}
5583.5	.00500	.250	1.3×10^{-9}
5679.3	.00500	.250	1.7×10^{-9}
5751.4	.00510	.255	1.7×10^{-9}
5847.5	.00515	.258	4.4×10^{-9}
5919.3	.00520	.260	2.0×10^{-9}
6039.4	.00530	.265	2.0×10^{-9}
6087.4	.00540	.270	1.8×10^{-9}
6183.4	.00545	.272	4.3×10^{-10}
6255.6	.00550	.275	4.5×10^{-10}
6351.8	.00550	.275	2.0×10^{-9}
6424.3	.00555	.278	2.4×10^{-9}

Test in progress.

TABLE VIII

CREEP TEST DATA, TZC PLATE, HEAT M-80, ANNEALED AT 3092°F (1700°C) FOR 1 HOUR, TESTED AT 2200°F (1204°C), 17,000 PSI (1.17 x 10^8 N/m^2)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
1 minutes	.00000	.000	5.7 x 10^{-9}
2	-.00020	-.010	
3	-.00030	-.015	
4	-.00020	-.010	
5	-.00020	-.010	
6	-.00015	-.008	
7	-.00015	-.008	
8	-.00015	-.008	
9	-.00005	-.002	
10	-.00015	-.008	
15	-.00015	-.008	
20	-.00015	-.008	
60	-.00015	-.008	
85.6 hours	.00165	.082	2.8 x 10^{-9}
108.9	.00160	.080	2.4 x 10^{-9}
133.1	.00180	.090	2.1 x 10^{-9}
229.1	.00245	.122	1.6 x 10^{-9}
254.0	.00240	.120	2.2 x 10^{-9}
277.0	.00260	.130	3.2 x 10^{-9}
301.5	.00265	.132	1.4 x 10^{-9}
325.2	.00265	.132	--
383.5	.00300	.150	1.5 x 10^{-9}
407.3	.00325	.162	2.6 x 10^{-9}
431.4	.00325	.162	2.4 x 10^{-9}
455.2	.00300	.150	1.2 x 10^{-9}
479.6	.00315	.158	3.2 x 10^{-9}
551.8	.00310	.155	1.4 x 10^{-9}
575.5	.00320	.160	1.2 x 10^{-9}
604.6	.00350	.175	--
623.4	.00370	.185	1.7 x 10^{-9}
648.5	.00380	.190	7.6 x 10^{-10}
719.2	.00390	.195	5.0 x 10^{-10}
743.7	.00390	.195	1.6 x 10^{-9}
767.6	.00395	.198	2.6 x 10^{-9}

TABLE VIII (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
791.2	.00410	.205	8.8×10^{-10}
815.2	.00430	.215	9.2×10^{-10}
887.2	.00455	.228	8.1×10^{-10}
911.2	.00465	.232	2.3×10^{-10}
935.5	.00475	.238	9.2×10^{-10}
959.4	.00475	.238	8.2×10^{-10}
983.5	.00480	.240	2.8×10^{-10}
1055.2	.00530	.265	1.0×10^{-9}
1109.8	.00550	.275	9.6×10^{-10}
1128.1	.00550	.275	9.3×10^{-10}
1151.5	.00565	.282	8.9×10^{-10}
1200.6	.00580	.290	1.4×10^{-9}
1247.2	.00590	.295	1.1×10^{-9}
1272.1	.00600	.300	8.8×10^{-10}
1295.3	.00615	.308	1.3×10^{-9}
1319.2	.00620	.310	7.9×10^{-10}
1391.2	.00690	.345	9.2×10^{-10}
1439.3	.00695	.348	4.6×10^{-10}
1487.3	.00690	.345	7.2×10^{-10}
1559.2	.00690	.345	4.9×10^{-9}
1612.0	.00705	.352	5.9×10^{-10}
1655.2	.00730	.365	5.0×10^{-10}
1727.1	.00785	.392	7.4×10^{-10}
1799.6	.00800	.400	5.6×10^{-10}
1895.5	.00820	.410	4.1×10^{-10}
1967.2	.00850	.425	4.5×10^{-10}
2087.5	.00885	.442	3.3×10^{-10}
2235.9	.00910	.455	6.0×10^{-10}
2331.4	.00910	.455	6.4×10^{-10}
2403.6	.00915	.458	4.0×10^{-10}
2499.7	.00915	.458	5.0×10^{-10}
2571.3	.01055	.528	4.0×10^{-10}
2670.2	.01060	.530	5.4×10^{-10}
2742.8	.01090	.545	3.8×10^{-10}

Test terminated because of leak.

TABLE IX

CREEP TEST DATA, TZC PLATE, HEAT M-80, RECRYSTALLIZED AT 3092°F (1700°C) FOR 1 HOUR, TESTED AT 2000°F (1093°C), 20,000 PSI ($1.38 \times 10^8 N/m^2$)

Time		Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
1	minutes	.00000	.000	1.2×10^{-9}
2		-.00020	-.010	
3		-.00040	-.020	
4		-.00030	-.015	
5		-.00030	-.015	
10		-.00005	-.002	
15		.00005	.002	
20		.00005	.002	
25		.00010	.005	
30		.00010	.005	
60		.00005	.002	
90		-.00005	-.002	
17.2	hours	.00040	.020	2.6×10^{-9}
41.3		.00060	.030	2.2×10^{-9}
65.2		.00080	.040	2.2×10^{-9}
89.2		.00115	.058	2.0×10^{-9}
161.3		.00110	.055	1.3×10^{-9}
185.7		.00130	.065	1.7×10^{-9}
209.1		.00125	.068	1.7×10^{-9}
233.2		.00125	.062	1.4×10^{-9}
257.3		.00130	.065	1.3×10^{-9}
329.2		.00140	.070	2.0×10^{-9}
355.9		.00145	.072	3.2×10^{-9}
377.0		.00145	.072	3.4×10^{-9}
401.1		.00145	.072	2.4×10^{-9}
425.0		.00150	.075	1.5×10^{-9}
497.2		.00170	.085	1.9×10^{-9}
521.4		.00170	.085	3.1×10^{-9}
545.4		.00165	.082	4.8×10^{-9}
569.2		.00170	.085	4.5×10^{-9}
593.1		.00170	.085	4.6×10^{-9}
665.2		.00165	.082	5.0×10^{-9}
713.3		.00160	.080	4.6×10^{-9}
762.8		.00170	.085	--
833.4		.00175	.088	1.5×10^{-8}
881.4		.00185	.092	6.1×10^{-9}
905.2		.00175	.088	5.8×10^{-9}

TABLE IX (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1001.1 hours	.00185	.092	3.9×10^{-9}
1049.2	.00185	.092	6.4×10^{-9}
1097.3	.00190	.095	--
1168.4	.00195	.098	4.2×10^{-9}
1216.2	.00200	.100	7.5×10^{-9}
1264.3	.00195	.098	7.0×10^{-9}
1336.7	.00210	.105	7.5×10^{-9}
1389.5	.00250	.125	--
1433.4	.00255	.128	7.2×10^{-9}
1504.2	.00260	.130	1.3×10^{-8}
1552.3	.00270	.135	1.2×10^{-8}
1600.2	.00265	.132	2.6×10^{-9}
1672.4	.00270	.135	5.5×10^{-9}
1720.4	.00275	.138	3.8×10^{-9}
1768.5	.00285	.142	4.6×10^{-9}
1840.1	.00305	.152	4.4×10^{-9}
1894.6	.00310	.155	4.4×10^{-9}
1936.3	.00315	.158	3.8×10^{-9}
1985.6	.00310	.155	3.8×10^{-9}
2032.2	.00325	.162	4.0×10^{-9}
2057.0	.00330	.165	4.0×10^{-9}
2104.1	.00335	.168	3.8×10^{-9}
2176.1	.00345	.172	3.5×10^{-9}
2248.4	.00370	.185	4.2×10^{-9}
2272.2	.00360	.180	7.5×10^{-9}
2344.2	.00375	.188	2.4×10^{-9}
2396.9	.00380	.190	4.6×10^{-9}
2440.2	.00390	.195	4.4×10^{-9}
2512.0	.00400	.200	2.7×10^{-9}
2584.4	.00400	.200	2.9×10^{-9}
2680.2	.00400	.200	7.4×10^{-9}
2752.2	.00405	.202	5.4×10^{-9}
2872.4	.00415	.208	3.8×10^{-9}
2920.8	.00420	.210	6.2×10^{-9}
3016.1	.00425	.212	3.8×10^{-9}
3088.4	.00435	.218	2.6×10^{-9}
3184.6	.00440	.220	4.2×10^{-9}
3256.3	.00450	.225	4.4×10^{-9}

TABLE IX (Continued)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
3355.4 hours	.00460	.230	--
3429.1	.00460	.230	--
3530.3	.00490	.245	--
3593.5	.00495	.247	7.8×10^{-9}
3689.9	.00500	.250	8.0×10^{-9}
3760.5	.00510	.255	8.0×10^{-9}
3856.2	.00515	.257	8.2×10^{-9}
3928.5	.00525	.262	8.2×10^{-9}
4024.1	.00575	.282	8.7×10^{-9}
4096.3	.00620	.310	8.2×10^{-9}
4192.3	.00640	.320	8.2×10^{-9}
4264.1	.00640	.320	8.2×10^{-9}
4384.3	.00640	.320	8.4×10^{-9}
4432.3	.00640	.320	9.0×10^{-9}
4528.3	.00630	.315	8.6×10^{-9}
4600.5	.00640	.320	9.4×10^{-9}
4696.7	.00625	.312	9.5×10^{-9}
4769.2	.00640	.320	8.5×10^{-9}

Test in Progress.

TABLE X

CREEP TEST DATA, TZC PLATE, RECRYSTALLIZED AT 3092°F (1700°C), FOR 1 HOUR, TESTED AT 1856°F (1013°C). 25,000 psi (1.72×10^8 N/m^2)
HEAT M-80

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1 minute(s)	-.00005	-.002	
2	.00000	.000	
3	-.00005	-.002	
4	.00005	.002	
5	.00005	.002	
6	.00010	.005	
7	.00005	.002	
8	.00000	.000	
9	.00000	.000	
10	.00005	.002	
15	-.00005	-.002	
20	.00015	.008	
25	.00015	.008	
30	.00025	.012	
60	.00065	.032	
19.3 hours	.00085	.042	1.4×10^{-8}
42.1	.00095	.048	1.3×10^{-8}
68.2	.00095	.048	1.1×10^{-8}
138.4	.00090	.045	5.8×10^{-9}
162.8	.00085	.042	6.6×10^{-9}
186.0	.00085	.042	6.8×10^{-9}
210.3	.00080	.040	5.8×10^{-9}
306.2	.00075	.038	5.2×10^{-9}
330.2	.00090	.045	4.4×10^{-9}
354.2	.00085	.042	3.4×10^{-9}
381.6	.00095	.048	--
402.4	.00095	.048	3.6×10^{-9}
460.7	.00105	.052	2.5×10^{-9}
484.5	.00105	.052	2.8×10^{-9}
508.5	.00125	.062	3.4×10^{-9}
532.4	.00105	.052	3.8×10^{-9}
556.8	.00105	.052	3.2×10^{-9}
628.9	.00105	.052	3.0×10^{-9}
681.7	.00115	.058	--
725.6	.00125	.062	3.1×10^{-9}
796.4	.00130	.065	2.0×10^{-9}
844.8	.00145	.072	2.2×10^{-9}
892.4	.00145	.072	1.6×10^{-9}
964.6	.00140	.070	2.8×10^{-9}

TABLE XI

CREEP TEST DATA, VAPOR DEPOSITED TUNGSTEN, RECRYSTALLIZED 2 HOURS 3200°F (1760°C), TESTED AT 3200°F (1760°C), 1000 PSI ($6.90 \times 10^6 N/m^2$)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
1 minutes	.00010	.005	
2	.00070	.035	
3	.00110	.055	
6	.00120	.060	
14	.00100	.050	
20	.00105	.052	3.8×10^{-7}
40	.00110	.055	
60	.00160	.080	
16.3 hours	.00220	.110	1.2×10^{-7}
88.4	.00460	.230	7.2×10^{-8}
117.4	.00550	.275	6.7×10^{-8}
136.6	.00675	.338	1.8×10^{-8}
160.3	.00755	.378	3.0×10^{-8}
184.1	.00795	.398	8.9×10^{-9}
256.0	.00960	.480	1.4×10^{-8}
280.0	.00940	.470	7.9×10^{-9}
304.1	.01045	.522	6.7×10^{-9}
328.4	.01095	.548	8.2×10^{-9}
352.2	.01115	.558	1.2×10^{-8}
424.3	.01190	.595	5.2×10^{-9}
448.1	.01280	.640	4.7×10^{-9}
472.1	.01190	.595	6.5×10^{-9}
496.0	.01310	.655	6.6×10^{-9}
520.2	.01350	.675	6.0×10^{-9}
616.2	.01395	.698	5.9×10^{-9}
640.7	.01410	.705	5.6×10^{-9}
664.2	.01430	.715	7.8×10^{-9}
688.2	.01460	.730	4.9×10^{-9}
760.3	.01520	.760	4.0×10^{-9}
784.1	.01580	.790	5.4×10^{-9}
808.1	.01625	.812	5.2×10^{-9}
832.3	.01640	.820	5.0×10^{-9}
856.4	.01725	.862	--
928.5	.01750	.875	5.2×10^{-9}
952.4	.01760	.880	8.4×10^{-9}
976.2	.01710	.855	9.8×10^{-9}
991.0	.01800	.900	9.8×10^{-9}
1014.2	.01800	.900	9.5×10^{-9}

Test in Progress.

TABLE X (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1012.6 hours	.00155	.078	2.7×10^{-9}
1060.7	.00170	.085	2.6×10^{-9}
1132.3	.00165	.082	2.4×10^{-9}
1186.9	.00165	.082	2.0×10^{-9}
1228.6	.00170	.085	1.8×10^{-9}
1277.8	.00170	.085	2.2×10^{-9}
1324.4	.00165	.082	2.3×10^{-9}
1349.2	.00175	.088	1.4×10^{-9}
1396.3	.00185	.092	1.8×10^{-9}
1468.3	.00185	.092	2.5×10^{-9}
1516.4	.00180	.090	2.6×10^{-9}
1564.4	.00185	.092	3.1×10^{-9}
1636.4	.00195	.098	2.5×10^{-9}
1689.1	.00205	.102	2.2×10^{-9}
1732.4	.00195	.098	2.8×10^{-9}
1804.3	.00200	.100	2.0×10^{-9}
1876.7	.00215	.108	2.0×10^{-9}
1972.6	.00210	.105	2.3×10^{-9}
2044.4	.00225	.112	9.6×10^{-10}
2164.7	.00225	.112	2.5×10^{-9}
2213.1	.00235	.118	1.4×10^{-9}
2308.3	.00230	.115	1.2×10^{-9}
2380.7	.00235	.118	2.5×10^{-9}
2479.4	.00235	.118	1.2×10^{-9}
2548.4	.00235	.118	2.6×10^{-9}
2647.3	.00245	.122	1.8×10^{-9}
2720.0	.00245	.122	1.1×10^{-9}
2822.6	.00260	.130	9.1×10^{-10}
2886.4	.00305	.152	2.2×10^{-9}
2982.1	.00295	.148	1.6×10^{-9}
3052.8	.00320	.160	1.6×10^{-9}
3148.7	.00315	.158	1.6×10^{-9}
3220.7	.00315	.158	1.6×10^{-9}
3316.4	.00310	.155	1.9×10^{-9}
3388.8	.00315	.158	1.8×10^{-9}
3484.6	.00335	.168	1.6×10^{-9}
3556.4	.00330	.165	1.4×10^{-9}
3676.5	.00335	.168	1.5×10^{-9}
3724.5	.00330	.165	1.9×10^{-9}
3820.7	.00330	.165	1.6×10^{-9}
3892.7	.00320	.160	1.7×10^{-9}
3988.9	.00315	.158	2.8×10^{-9}
4061.4	.00315	.158	1.3×10^{-9}

Test in Progress.

TABLE X (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1012.6 hours	.00155	.078	2.7×10^{-9}
1060.7	.00170	.085	2.6×10^{-9}
1132.3	.00165	.082	2.4×10^{-9}
1186.9	.00165	.082	2.0×10^{-9}
1228.6	.00170	.085	1.8×10^{-9}
1277.8	.00170	.085	2.2×10^{-9}
1324.4	.00165	.082	2.3×10^{-9}
1349.2	.00175	.088	1.4×10^{-9}
1396.3	.00185	.092	1.8×10^{-9}
1468.3	.00185	.092	2.5×10^{-9}
1516.4	.00180	.090	2.6×10^{-9}
1564.4	.00185	.092	3.1×10^{-9}
1636.4	.00195	.098	2.5×10^{-9}
1689.1	.00205	.102	2.2×10^{-9}
1732.4	.00195	.098	2.8×10^{-9}
1804.3	.00200	.100	2.0×10^{-9}
1876.7	.00215	.108	2.0×10^{-9}
1972.6	.00210	.105	2.3×10^{-9}
2044.4	.00225	.112	9.6×10^{-10}
2164.7	.00225	.112	2.5×10^{-9}
2213.1	.00235	.118	1.4×10^{-9}
2308.3	.00230	.115	1.2×10^{-9}
2380.7	.00235	.118	2.5×10^{-9}
2479.4	.00235	.118	1.2×10^{-9}
2548.4	.00235	.118	2.6×10^{-9}
2647.3	.00245	.122	1.8×10^{-9}
2720.0	.00245	.122	1.1×10^{-9}
2822.6	.00260	.130	9.1×10^{-10}
2886.4	.00305	.152	2.2×10^{-9}
2982.1	.00295	.148	1.6×10^{-9}
3052.8	.00320	.160	1.6×10^{-9}
3148.7	.00315	.158	1.6×10^{-9}
3220.7	.00315	.158	1.6×10^{-9}
3316.4	.00310	.155	1.9×10^{-9}
3388.8	.00315	.158	1.8×10^{-9}
3484.6	.00335	.168	1.6×10^{-9}
3556.4	.00330	.165	1.4×10^{-9}
3676.5	.00335	.168	1.5×10^{-9}
3724.5	.00330	.165	1.9×10^{-9}
3820.7	.00330	.165	1.6×10^{-9}
3892.7	.00320	.160	1.7×10^{-9}
3988.9	.00315	.158	2.8×10^{-9}
4061.4	.00315	.158	1.3×10^{-9}

Test in Progress.

TABLE XI

CREEP TEST DATA, VAPOR DEPOSITED TUNGSTEN, RECRYSTALLIZED 2 HOURS 3200°F (1760°C), TESTED AT 3200°F (1760°C), 1000 PSI ($6.90 \times 10^6 N/m^2$)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
1 minutes	.00010	.005	
2	.00070	.035	
3	.00110	.055	
6	.00120	.060	
14	.00100	.050	
20	.00105	.052	3.8×10^{-7}
40	.00110	.055	
60	.00160	.080	
16.3 hours	.00220	.110	1.2×10^{-7}
88.4	.00460	.230	7.2×10^{-8}
117.4	.00550	.275	6.7×10^{-8}
136.6	.00675	.338	1.8×10^{-8}
160.3	.00755	.378	3.0×10^{-8}
184.1	.00795	.398	8.9×10^{-9}
256.0	.00960	.480	1.4×10^{-8}
280.0	.00940	.470	7.9×10^{-9}
304.1	.01045	.522	6.7×10^{-9}
328.4	.01095	.548	8.2×10^{-9}
352.2	.01115	.558	1.2×10^{-8}
424.3	.01190	.595	5.2×10^{-9}
448.1	.01280	.640	4.7×10^{-9}
472.1	.01190	.595	6.5×10^{-9}
496.0	.01310	.655	6.6×10^{-9}
520.2	.01350	.675	6.0×10^{-9}
616.2	.01395	.698	5.9×10^{-9}
640.7	.01410	.705	5.6×10^{-9}
664.2	.01430	.715	7.8×10^{-9}
688.2	.01460	.730	4.9×10^{-9}
760.3	.01520	.760	4.0×10^{-9}
784.1	.01580	.790	5.4×10^{-9}
808.1	.01625	.812	5.2×10^{-9}
832.3	.01640	.820	5.0×10^{-9}
856.4	.01725	.862	--
928.5	.01750	.875	5.2×10^{-9}
952.4	.01760	.880	8.4×10^{-9}
976.2	.01710	.855	9.8×10^{-9}
991.0	.01800	.900	9.8×10^{-9}
1014.2	.01800	.900	9.5×10^{-9}

Test in Progress.

TABLE XII

CREEP TEST DATA, TZC PLATE, HEAT M-80, RECRYSTALLIZED AT 3092°F (1700°C), 1 HOUR, TESTED AT 2056°F (1124°C), 19,000 PSI (1.31 x $10^8 N/m^2$)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1 minutes	.00010	.005	7.0 x 10^{-8}
2	.00020	.010	
3	.00030	.015	
4	.00050	.025	
5	.00055	.028	
6	.00065	.032	
7	.00085	.042	
8	.00095	.048	
9	.00105	.052	
10	.00120	.060	
12	.00130	.065	
13	.00140	.070	
14	.00150	.075	
15	.00160	.080	6.9 x 10^{-8}
20	.00165	.082	
25	.00170	.085	
30	.00170	.085	6.9 x 10^{-8}
40	.00175	.088	
45	.00175	.088	
60	.00180	.090	6.8 x 10^{-8}
90	.00180	.090	6.7 x 10^{-8}
15.7 hours	.00180	.090	3.5 x 10^{-8}
87.1	.00180	.090	1.4 x 10^{-8}
111.2	.00100	.050	9.8 x 10^{-9}
133.4	.00140	.070	7.0 x 10^{-9}
159.0	.00135	.068	3.0 x 10^{-9}
181.6	.00130	.065	--
239.9	.00135	.068	4.2 x 10^{-9}
263.7	.00130	.065	5.1 x 10^{-9}
287.7	.00150	.075	4.5 x 10^{-9}
309.9	.00140	.070	3.8 x 10^{-9}
334.3	.00150	.075	3.2 x 10^{-9}
406.5	.00145	.072	3.5 x 10^{-9}
459.3	.00155	.078	--
503.2	.00150	.075	2.2 x 10^{-9}
573.9	.00175	.088	1.2 x 10^{-9}

TABLE XII (Continued)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
622.5 hours	.00175	.088	1.1×10^{-9}
669.9	.00180	.090	3.8×10^{-9}
742.3	.00185	.092	2.8×10^{-9}
790.2	.00190	.095	2.8×10^{-9}
838.3	.00185	.092	1.8×10^{-9}
909.9	.00195	.098	3.2×10^{-9}
964.8	.00205	.102	2.6×10^{-9}
1006.2	.00210	.105	2.6×10^{-9}
1055.3	.00215	.108	2.7×10^{-9}
1102.0	.00220	.110	2.9×10^{-9}
1126.8	.00220	.110	1.7×10^{-9}
1173.9	.00220	.110	1.0×10^{-9}
1245.9	.00215	.108	4.2×10^{-10}
1294.0	.00225	.112	2.1×10^{-9}
1342.0	.00235	.118	2.1×10^{-10}
1414.1	.00235	.118	1.4×10^{-9}
1466.7	.00235	.118	2.5×10^{-9}
1509.0	.00225	.112	2.0×10^{-9}
1581.8	.00245	.122	7.5×10^{-10}
1654.2	.00245	.122	1.2×10^{-9}
1750.2	.00240	.120	1.3×10^{-9}
1822.1	.00235	.118	7.0×10^{-10}
1942.2	.00235	.118	8.4×10^{-10}
1990.6	.00240	.120	7.4×10^{-10}
2086.2	.00250	.125	1.6×10^{-9}
2158.2	.00260	.130	1.4×10^{-9}
2254.4	.00265	.132	7.2×10^{-10}
2326.1	.00265	.132	2.0×10^{-9}
2424.7	.00280	.140	1.4×10^{-9}
2497.4	.00305	.152	1.2×10^{-9}
2600.1	.00310	.155	8.0×10^{-10}
2664.7	.00325	.162	2.4×10^{-9}
2759.8	.00345	.172	2.6×10^{-9}
2854.3	.00355	.178	1.5×10^{-9}
2926.3	.00355	.178	1.5×10^{-9}
2998.2	.00355	.178	2.1×10^{-9}
3094.0	.00365	.182	2.1×10^{-9}
3166.4	.00360	.180	2.2×10^{-9}
3262.2	.00355	.178	9.2×10^{-9}

TABLE XII (Continued)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
3334.1 hours	.00360	.180	2.2×10^{-9}
3454.1	.00340	.170	1.6×10^{-9}
3502.1	.00365	.182	2.0×10^{-9}
3598.2	.00315	.158	1.1×10^{-9}
3670.3	.00315	.158	1.0×10^{-9}
3766.6	.00300	.150	9.0×10^{-10}
3839.0	.00305	.152	2.5×10^{-9}

Test in Progress.

TABLE XIII

CREEP TEST DATA, Cb-132M PLATE, ANNEALED AT 3092°F (1700°C), FOR 1 HOUR, TESTED AT 2256°F (1232°C), 7,400 PSI (5.10×10^7 N/m^2) HEAT KC-1454

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1 minute(s)	.00005	.002	2.0×10^{-7}
2	.00005	.002	
3	.00000	.000	
4	.00005	.002	
5	.00000	.000	
6	.00000	.000	
7	.00000	.000	
8	.00000	.000	
9	.00005	.002	
10	.00000	.000	
20	.00000	.000	
35	.00050	.025	
60	.00055	.028	
1.5 hours	.00050	.025	
2.0	.00055	.028	
17.7	.00155	.078	2.9×10^{-8}
90.2	.00460	.230	1.4×10^{-8}
114.0	.00520	.260	1.4×10^{-8}
137.9	.00575	.288	6.4×10^{-9}
161.9	.00680	.340	7.5×10^{-9}
186.0	.00775	.388	--
258.5	.01015	.508	3.0×10^{-9}
332.2	.01340	.670	4.9×10^{-9}
435.9	.01660	.830	1.9×10^{-9}
500.5	.01810	.905	3.1×10^{-9}
595.5	.02200	1.100	2.5×10^{-9}

Test Terminated After Reaching 1% Creep.

TABLE XIV

CREEP TEST DATA, T-222 SHEET, ANNEALED 3000°F (1649°C), 1 HOUR, TESTED AT 2056°F (1124°C), 19,200 PSI($1.32 \times 10^8 N/m^2$)

HEAT AL TA 43

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
1 minutes	.00000	.000	
3	.00015	.008	
8	.00015	.008	
13	.00015	.008	
1.0 hours	.00015	.008	3.0×10^{-9}
18.6	.00015	.008	--
40.5	.00030	.015	5.7×10^{-9}
137.2	.00065	.032	1.6×10^{-9}
159.8	.00090	.045	1.4×10^{-9}
183.6	.00140	.070	1.4×10^{-9}
207.8	.00190	.095	3.3×10^{-9}
231.8	.00230	.115	3.1×10^{-9}
303.7	.00340	.170	1.2×10^{-9}
328.9	.00480	.240	1.3×10^{-9}
351.5	.00540	.270	9.5×10^{-10}
375.8	.00565	.282	8.4×10^{-10}
399.5	.00610	.305	1.2×10^{-9}
471.4	.00755	.378	1.4×10^{-9}
495.5	.00845	.422	1.0×10^{-9}
519.5	.00915	.458	1.0×10^{-9}
543.6	.00965	.482	1.2×10^{-9}
567.6	.01005	.502	1.2×10^{-9}
663.6	.01230	.615	1.4×10^{-9}
687.6	.01305	.652	1.3×10^{-9}
711.5	.01410	.707	1.3×10^{-9}
735.7	.01485	.742	1.4×10^{-9}
831.6	.01830	.915	1.4×10^{-9}
856.2	.01895	.948	9.2×10^{-10}
879.6	.01970	.985	1.0×10^{-9}
903.6	.02095	1.042	9.5×10^{-10}
975.6	.02310	1.155	9.2×10^{-10}
999.6	.02385	1.192	9.5×10^{-10}
1023.5	.02465	1.232	1.0×10^{-9}
1047.8	.02550	1.275	9.0×10^{-10}
1144.0	.02935	1.468	9.5×10^{-10}
1216.4	.03215	1.608	5.4×10^{-10}

Test in Progress.

TABLE XV

CREEP TEST DATA, T-222 SHEET, ANNEALED 3000°F (1649°C), 1 HOUR, TESTED AT 2200°F (1204°C), 12,000 PSI (8.27 x $10^7 N/m^2$)

HEAT AL TA 43

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
1 minutes	.00020	.010	2.8 x 10^{-9}
2	.00070	.035	
3	.00060	.030	
4	.00060	.030	
5	.00065	.032	
6	.00060	.030	
7	.00070	.035	
8	.00060	.030	
9	.00060	.030	
10	.00070	.035	
15	.00070	.035	
45	.00080	.040	
1.0 hours	.00075	.038	2.8 x 10^{-9}
17.7	.00110	.055	2.0 x 10^{-9}
41.2	.00120	.060	1.6 x 10^{-9}
65.0	.00140	.070	1.5 x 10^{-9}
136.9	.00230	.115	1.5 x 10^{-9}
160.9	.00345	.172	1.2 x 10^{-9}
184.9	.00370	.185	1.3 x 10^{-9}
209.0	.00435	.218	3.2 x 10^{-9}
232.9	.00505	.252	3.4 x 10^{-9}
305.1	.00775	.388	1.0 x 10^{-9}
328.9	.00865	.432	2.5 x 10^{-9}
353.0	.00980	.490	8.7 x 10^{-10}
376.8	.01080	.540	2.5 x 10^{-9}
401.0	.01165	.582	2.4 x 10^{-9}
497.0	.01535	.768	8.0 x 10^{-10}
521.6	.01625	.812	8.0 x 10^{-10}
545.0	.01715	.858	8.1 x 10^{-10}
569.0	.01785	.892	7.8 x 10^{-10}
641.0	.02145	1.072	2.1 x 10^{-9}
664.9	.02250	1.125	2.0 x 10^{-9}
688.9	.02360	1.180	2.0 x 10^{-9}
713.2	.02540	1.270	2.0 x 10^{-9}
737.0	.02640	1.320	--
809.4	.03035	1.518	6.0 x 10^{-10}
833.2	.03140	1.570	1.8 x 10^{-9}
857.1	.03320	1.660	1.7 x 10^{-9}
881.8	.03440	1.720	5.0 x 10^{-9}
905.0	.03580	1.790	5.5 x 10^{-10}

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